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MANUAL ON PRESERVATIVE TREATMENT OF WOOD BY PRESSURE

By

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Forest Service

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INTRODUCTION

The amount of timber treated with preservatives in the 10-year period from 1921 to 1930 averaged over 280,000,000 cubic feet per

[1] Acknowledgment is made to various members of the Forest Products Laboratory who have been consulted on subjects relating to their fields of investigation and from whom much helpful data and information have been obtained.
[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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year. This was nearly twice as much as the annual average in the preceding decade. It is probable that the use of treated wood will show a still greater increase in the future as the economy resulting from preservative treatment becomes better known. Preservative treatments protect wood where it is exposed to destruction by decay, insects, or marine borers. The savings effected by such treatments include lower annual cost and more satisfactory service of wood for railway ties, bridges, pole lines, piers, and many other wood structures as well as a decreased drain upon the forest resources of the United States.

The effectiveness and economy of preservative treatment depend chiefly upon its thoroughness. Good treatment intelligently used is economical, but poor treatment, whether resulting from improper choice of preservative, improper specifications, low absorptions, or insufficient penetration in the treating operation, is expensive and may prove disastrous.

The problem of adequate treatment is complicated by many factors, including the species, size, form, condition, and proposed use of the timber; kind and amount of preservative to be injected; details of the treating process employed; and the skill of the treating-plant operator. The methods now in use for the injection of preservatives by pressure processes [3] are the result partly of technical research and partly of the accumulation of nearly a century of world experience in wood preservation. Much improvement has been made in recent years so that it is practicable for purchasers to obtain adequately treated timber that can be depended on for long life under the most severe conditions of exposure.

The Forest Products Laboratory has done much work on the many technical problems involved in the pressure treatment of wood, including numerous experiments and observations at commercial treating plants. The purpose of this publication is to discuss the application of the results of these experiments and observations to the improvement of the pressure treatment of wood and to present general information relating to the subject. Such information is of value to engineers, treating-plant operators, inspectors, and others interested in the preparation of specifications and in the application of pressure-treating processes.

PRESSURE PROCESSES

The most effective method of treating wood with preservatives is by means of pressure. There are a number of pressure processes, all of which employ the same general principle but differ in the details of application. The timber to be treated is loaded on tram cars which are run into a large steel cylinder. After the cylinder door is closed and bolted shut, preservative is admitted and pressure applied until the required absorption has been obtained. Two principal types of pressure treatment, the full-cell (Bethell) and empty-cell, are in common use.

FULL-CELL PROCESS

In making treatments with the full-cell or Bethell process, a preliminary vacuum is first applied to remove as much air as prac-

[3] The treatment of timber by open-tank and other nonpressure methods is discussed in Farmer's Bulletin 744 (*10*). [4]

[4] Italic numbers in parentheses refer to Literature Cited, p. 115.

ticable from the wood cells. The preservative is then admitted without admitting air. After the cylinder is filled with preservative, pressure is applied until the required absorption is obtained. A final vacuum is commonly applied immediately after the cylinder has been emptied of preservative to free the charge of dripping preservative.

When the timber is given a preliminary steaming and vacuum treatment (p. 30) the preservative is admitted at the end of the vacuum period following steaming. In case the charge has received a preliminary treatment by the Boulton or boiling-under-vacuum process (p. 49) the unfilled space at the top of the cylinder is filled with preservative and pressure is applied as soon as this conditioning process has been completed.

It is impossible to remove all of the air from the wood cells regardless of the method of treatment employed. For this reason even under the most favorable conditions there is some unfilled air space in the cell cavities of the treated wood after impregnation by the so-called "full-cell" process.

When the full-cell process is used for treatment with zinc-chloride solution it is commonly called the "Burnett process."

EMPTY-CELL PROCESSES

The empty-cell process consists of forcing preservative into the wood cells when they are filled with air. When the preservative pressure is released the confined air, which is under pressure, drives out part of the preservative absorbed during treatment, leaving a lower net absorption than would be obtained with the full-cell process. Good treatment depends very largely on the depth of penetration and the latter is, in a general way, proportional to the gross absorption.

Two empty-cell treatments, the Lowry and the Rueping, are commonly used, both of which depend upon compressed air in the wood to force part of the absorbed preservative out of the cell cavities after pressure has been released. When the cylinder is filled with preservative, pressure is applied the same as in the full-cell process. After the pressure treatment is completed the preservative is withdrawn from the cylinder and a final vacuum is applied.

The cells of treated wood are necessarily partly filled with preservative after treatment by the so-called "empty-cell" process. The difference between full-cell and empty-cell treatment, therefore, is merely a difference in the degree to which the cell cavities are left filled after treatment.

LOWRY PROCESS

In the Lowry process, which is also designated as "empty-cell process without initial air", the preservative is admitted to the treating cylinder at atmospheric pressure. When the cylinder is filled, pressure is applied and the preservative is forced into the wood against the air originally in the cell cavities. After the required absorption has been obtained pressure is released and the air under pressure in the wood forces out part of the preservative absorbed during the pressure period. This makes it possible, with a limited net retention, to inject a greater amount of preservative into the wood and obtain deeper penetration than with the full-cell process. The Lowry process is convenient to use in any pressure-treating plant, since no additional equipment is required.

RUEPING PROCESS

The principal difference between the Lowry empty-cell process and the Rueping process is that the latter employs air pressure above atmospheric. In the Rueping process air is forced into the treating cylinder before the preservative is admitted. The air pressure is then maintained while the cylinder is filled with preservative, thus leaving the wood cells more or less impregnated with air under pressure. In resistant woods this air pressure may penetrate only a short distance from the surface, while in wood that is fairly pervious to the penetration of air and liquids, such as the sapwood of many species, an air pressure is built up in all of the penetrable portion. In the application of this process the preservative is usually admitted from an equalizing tank (Rueping tank) and the air in the treating cylinder interchanges with the preservative in this tank. In some plants not equipped with a Rueping tank the preservative is pumped into the treating cylinder against the air pressure and sufficient air is released during the filling period to keep the pressure constant. Impregnation of the wood is obtained by applying a preservative pressure sufficiently high to force preservative into the timber against the initial air pressure in the wood cells. This process is also called "empty-cell process with initial air."

WOOD PRESERVATIVES

Wood preservatives may be grouped into three general classes: (1) Those commonly called "preservative oils", which are relatively insoluble in water; (2) salts injected into the wood in the form of water solutions; and (3) those in which the toxic material is combined with a solvent, usually volatile, other than water.

The effectiveness of any preservative depends not only upon the materials of which it is composed but also upon the quantity injected into the wood and the depth of penetration obtained.

COAL-TAR CREOSOTE

Coal-tar creosote is defined [5] as a preservative oil obtained by the distillation—

> of coal tar produced by high-temperature carbonization of bituminous coal; it consists principally of liquid and solid aromatic hydrocarbons and contains appreciable quantities of tar acids and tar bases; it is heavier than water; and has a continuous boiling range of at least 125° C. beginning at about 200°.

Coal-tar creosote is highly effective and is the most important and most extensively used wood preservative for general purposes.

WATER-GAS TAR AND WATER-GAS-TAR CREOSOTE

Water-gas tar is obtained from petroleum oil as a byproduct in the manufacture of water gas.

Water-gas-tar creosote is produced by distillation from water-gas tar. This creosote is defined as any and all distillate oils from such tars boiling between 200° and 400° C. While water-gas tar and the creosote produced from it are not considered so generally effective as coal-tar creosote, service test records indicate that they have good preservative properties.

[5] American Wood Preservers' Association, manual of recommended practices, 47a, glossary of terms used in wood preservation. (Loose leaf.)

WOOD-TAR CREOSOTE

Wood-tar creosote is obtained from wood tar and distills mostly above 170° C. Since wood-tar creosotes have been produced in comparatively small quantities and have usually sold at higher prices than coal-tar creosote, they have not been extensively used as a wood preservative. It is not known how well their preservative qualities compare with those of coal-tar creosote but they possess good toxic properties.

COAL TARS

The various coal tars are, in general, unsuitable for wood preservatives when used alone because their relatively high viscosity makes it difficult to obtain satisfactory penetrations.

PETROLEUM OILS

Petroleum oils, such as crude petroleum, topped petroleum, fuel oil, and used crank-case oil as a rule do not possess toxic properties to make them suitable as wood preservatives when used alone. Although in a few cases good results have apparently been obtained with petroleum oils, in other cases complete failure has resulted.

CREOSOTE-COAL-TAR SOLUTIONS

Coal tar is extensively employed in solution with coal-tar creosote for the treatment of ties and to some extent for other classes of timber. The coal-tar solutions are used principally in the Eastern and Southern States. Mixtures of coal tar and creosote commonly contain about 20 percent of tar by volume although some having as much as 40 to 50 percent of tar are used.

COAL-TAR CREOSOTE AND WATER-GAS-TAR MIXTURES

Water-gas tar has been used in place of coal tar in creosote mixtures for the treatment of various kinds of material but more particularly for ties. The proportion of water-gas tar used in such mixtures has varied over a wide range depending upon the quality of tar and other factors.

COAL-TAR CREOSOTE AND PETROLEUM MIXTURES

Mixtures of coal-tar creosote and petroleum are widely used in the Western and Rocky Mountain States principally for the treatment of ties. These mixtures in general contain from 30 to 60 percent of petroleum by volume but more often the proportion is about 50 percent.

Since the toxicity of the petroleum mixtures is furnished by the creosote it is important that for this purpose the creosote does not run too high in residue above 355° F.

WATER-SOLUBLE SALTS

A variety of water-soluble salts are used as wood preservatives. These include zinc chloride, sodium fluoride, arsenic in various forms, copper sulphate, mercuric chloride, and similar toxic chemi-

cals. Some of these salts are also used in combination with other preservatives.

Zinc chloride is the water-soluble salt most widely used in the United States, the total consumption being greater than that of all other preservative salts combined. The more important advantages of this salt are its relative cheapness, uniformity of quality, cleanliness, lack of odor, ability to take and hold paint, and freedom from fire hazard. Its principal disadvantage is that common to all water-soluble salts, namely, its tendency when exposed to wet or damp conditions to leach out of the wood more rapidly than preservative oils.

Sodium fluoride has been used to some extent in the United States for experimental ties and factory roofs. It has also been used in mixture with other chemicals in Europe for mine timbers and other material. Results thus far obtained indicate that it has good preservative qualities. It is an important ingredient in several proprietary preservatives. Some of the latter are finding considerable use in the treatment of building lumber and structural timber.

Arsenic, either alone or mixed with other materials, has been used as a preservative for a number of years. It is still too early to tell how effective the various arsenic salts and compounds will prove to be in comparison with other preservatives. Some of them have shown promising results.

Copper sulphate has been extensively used in Europe and is known to be effective in retarding decay. It is not more effective than zinc chloride or sodium fluoride, however, and has no particular advantage over them. On the other hand, it is more corrosive to steel and cannot be used in ordinary treating equipment. It has not been used to an appreciable extent for wood preservation in the United States.

Mercuric chloride possesses excellent toxic properties and while it has been used to a considerable extent in some parts of Europe it is used very little in the United States. Some of its principal disadvantages are its relatively high cost, its extremely poisonous character, and its corrosiveness to metal.

CHEMICALS DISSOLVED IN SOLVENTS OTHER THAN WATER

Preservatives composed of chemicals carried in nonaqueous solvents are of recent origin and have been devised mainly for the purpose of providing a clean treatment without causing swelling of the wood. Their degree of effectiveness and the extent of their usefulness are not yet established by long service tests. At present they are employed only in nonpressure treatments.

PROPRIETARY PRESERVATIVES

Various patented or proprietary preservatives are sold under trade names. In some cases they are ordinary coal-tar creosote or coal-tar creosote from which certain ingredients have been removed, making them higher boiling and therefore less volatile than ordinary creosote, and some contain wood-tar products or other oils.

A number of proprietary preservatives are composed of various soluble salts and are injected in water solutions. Others employ a volatile solvent to carry the toxic substance into the wood.

The manufacturers of some proprietary preservatives tell the composition of the materials used whereas others do not. It is unwise to accept any preservative sold under a trade name without knowing the kind and amount of the preservative chemicals contained in the mixture. Extravagant claims are often made regarding the merits of some of these proprietary preservatives and the purchaser should insist upon knowing their composition. Some of these products have advantages for particular purposes.

EFFECT OF WOOD STRUCTURE ON TREATMENT

Wood varies greatly in its structure. Hardwoods differ from softwoods and in each of these groups there are differences among individual species. In fact, there are differences even in the same tree since the heartwood, although its gross structure is the same, commonly has certain substances not abundant in the sapwood. All these differences have their influence upon the penetrability of the wood by preservatives. An acquaintance with the following features of the structure of wood is needed for a full understanding and appreciation of this publication.

DIFFERENCES IN STRUCTURE OF HARDWOODS AND SOFTWOODS

Hardwood or broadleaf trees contain specialized cells which serve for sap conduction. These cells, set end to end, are known as pores or vessels, and form more or less continuous passages. Mechanical support is furnished by wood fibers which surround the vessels.

The softwoods, generally known as conifers,[6] do not have the specialized sap-conducting cells found in the hardwoods but instead have elongated cells called tracheids or fibers which have closed ends. These tracheids serve both for sap conduction and for mechanical support in the living tree. Liquids pass from one tracheid to another through bordered pits, which contain minute perforations and are most numerous near the tracheid ends.

The terms hardwood and softwood are somewhat misleading as there are some softwoods that are even harder, from the mechanical standpoint, than some of the hardwoods. Although in general most of the hardwoods are actually very hard there are some woods of this group that are soft, such as basswood, willow, and cottonwood. Similarly, though most of the softwoods are relatively soft, some of them, like yew, Douglas fir, and longleaf pine, are very hard.

Figures 1 and 2 show the general structure of a hardwood and a softwood, respectively.

Hardwoods, such as gum, beech, birch, and basswood, in which the pores or vessels are of fairly uniform size and distribution are called diffuse-porous woods whereas those that have alternate layers of small and large pores, such as oak, elm, hickory, and chestnut, are called ring-porous woods. The penetrability of the hardwoods depends to a large extent on the open or closed condition of these pores or vessels. On the other hand, penetration in the softwoods is largely dependent on the permeability of the cell walls.

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[6] Native species include the pines, Douglas fir, the true firs, spruces, hemlocks, junipers, larches, cedars, cypress, redwood, and yew.

HEARTWOOD AND SAPWOOD

In general, the most universal structural difference that affects the penetration of preservatives in both hardwoods and softwoods is the difference between heartwood and sapwood. Young trees are nearly all sapwood but as they grow older the heartwood volume at the center gradually increases while new sapwood forms on the out-

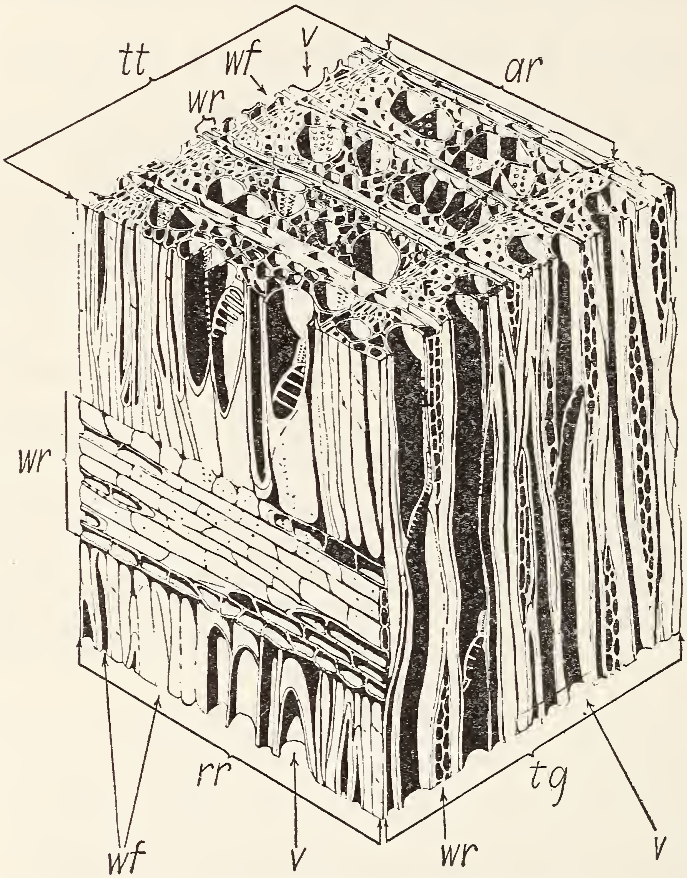

FIGURE 1.—Drawing of a highly magnified block of hardwood measuring about one-fortieth of an inch vertically: *tt*, End surface; *rr*, radial surface; *tg*, tangential surface; *v*, vessel or pore; *wf*, wood fibers; *wr*, wood rays; *ar*, annual ring.

side. The sapwood is living and takes an active part in the growth of the tree whereas the heartwood is dead or inactive. During this transition from sapwood to heartwood, changes generally occur in the pores of hardwoods, which may become partially or completely closed with pithlike growths called tyloses or with gum, while in the conifers the openings in the tracheid walls may undergo changes that make them highly resistant to the passage of liquids. The exact nature and the quantity of the various substances that accumulate in the heartwood are not well understood but it is known that their character differs materially in different species and their quantity

differs among different trees of the same species and even in different parts of the same tree. They are sometimes referred to under the all-inclusive expression "gums, resins, and infiltrated substances." Those that can be dissolved out of the wood by water or other solvents are collectively called "extractives." An infinite amount of

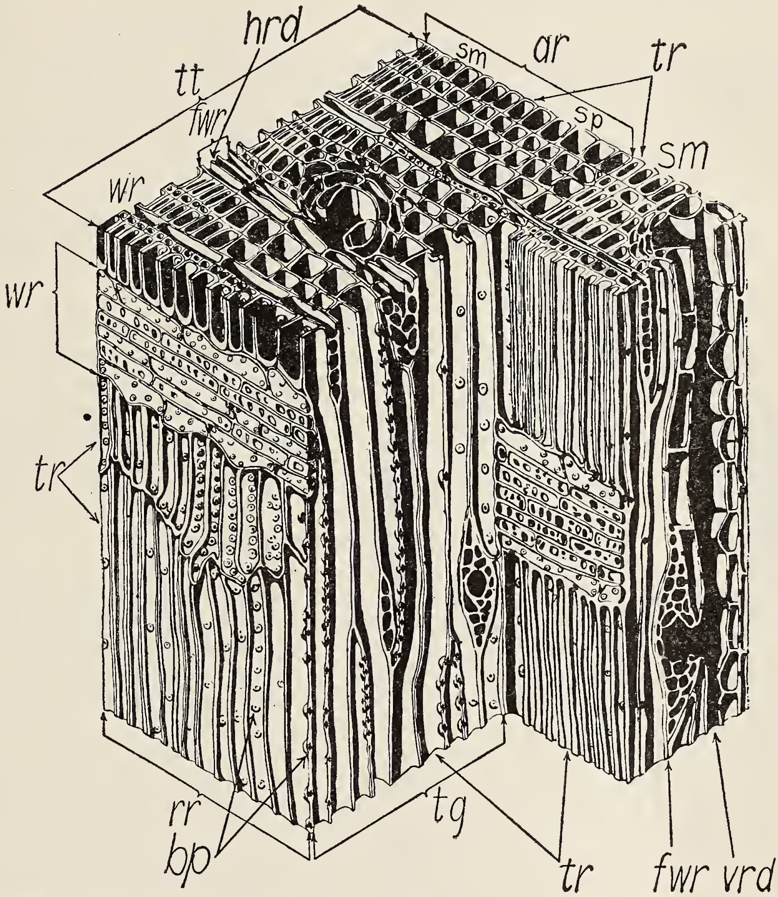

FIGURE 2.—Drawing of a highly magnified block of softwood measuring about one-fortieth of an inch vertically: *tt*, End surface; *rr*, radial surface; *tg*, tangential surface; *ar*, annual ring; *sm*, summer wood; *sp*, spring wood; *tr*, tracheids, or fibers; *hrd*, horizontal resin duct; *vrd*, vertical resin duct; *fwr*, fusiform wood ray or ray having horizontal resin ducts; *wr*, wood rays; *bp*, bordered pits.

painstaking chemical work would be required to identify all of the compounds included in these expressions.

Although the nature of the change from sapwood to heartwood is not fully understood, some of the major effects of the change are clearly evident. In most species there is a pronounced change to a darker color and the line of demarcation between heartwood and sapwood is distinct. However, in some species, like the hemlocks and spruces, there is little or no change in color. In some of the pines also it is not always easy to distinguish between heartwood and sapwood.

In a large number of species there is a marked superiority in the decay resistance of the heartwood in comparison with that of the sapwood. The sapwood of all species has low decay resistance whereas the heartwood of many is highly durable. The degree of durability evidently depends upon the amount and character of the substances that accumulate in the heartwood.

In most species the change from sapwood to heartwood greatly increases the resistance to penetration by preservatives but this, again, is not universally true. In some species, eastern hemlock for example, both the sapwood and heartwood are resistant and the sapwood offers nearly the same resistance to penetration as the heartwood. In ponderosa pine and bristlecone pine the heartwood is more resistant to decay than the sapwood but still not difficult to penetrate. In white oak, red gum, and beech with red heartwood, the heartwood is almost impenetrable by ordinary methods though the sapwood is easy to treat. These variations in penetrability affect the operation of treating plants, the selection of wood, and the preparation of specifications by purchasers.

A common fallacy is that the heartwood is materially stronger than the sapwood. The results of thousands of tests at the Forest Products Laboratory fail to show that this is true in any degree that is significant to the engineer interested in the preservative treatment of wood. The greater penetrability of the sapwood makes it superior from the standpoint of preservative treatment and it should usually be preferred rather than discriminated against in wood that is to be treated.

EFFECT OF TYLOSES ON PENETRATION

In some of the hardwoods, for example, white oak, chestnut, and black locust, the pores of the heartwood are filled with tyloses. Such species are usually resistant or almost impervious to treatment in the heartwood. In the sapwood, tyloses usually occur in the inner region near the heartwood where the vessels are beginning to lose their ability to conduct sap.

The influence of tyloses on penetration in the heartwood is illustrated by a comparison of the penetration obtained in the white oak group and in the red oak group. In most cases the heartwood of the white oaks is only slightly penetrable; that of the red oaks is, in general, readily penetrable. These two groups of species have practically the same wood structure with the exception that the vessels in white oak heartwood are plugged with tyloses whereas those of woods in the red oak group are usually free from tyloses. The other wood elements or fibers of these two groups of species are resistant to the penetration of liquids. The treatment of such species as red oak naturally depends to a large extent on penetration from the end surfaces. A discussion of penetration in the side surfaces is given on page 5. There are exceptional species, however, in both groups. For example, chestnut oak (*Quercus montana*) is a white oak that has relatively few tyloses. On the other hand, the red oak commonly called black jack or jack oak (*Q. marilandica*) has pores that are closed by tyloses and the species in this respect is similar to a white oak. Under certain growth conditions the other red oak species sometimes have a sporadic development of tyloses that may be of sufficient importance to impede penetration.

Experiments on various hardwoods show that when the wood fibers are resistant to penetration the presence or absence of tyloses or other obstructions, such as gums, in the vessels largely determines whether the wood can be impregnated with preservatives (*3*, *31*). Tyloses may have limited importance, however, and merely impede penetration in species where they do not completely fill the pores. This is true in some of the ashes.

In some of the diffuse porous woods, such as aspen and willow, tyloses occur more or less irregularly. Their influence in such species is, in general, proportional to their distribution. Diffuse porous woods that are resistant to treatment appear to exhibit more erratic penetrations than do the ring-porous woods, possibly on account of the irregular distribution of tyloses or gums. Among such species are the maples, sycamore, and largetooth aspen.

When the vessels or pores of a hardwood are filled with tyloses or gums so that the movement of liquids through them is completely obstructed, penetration must be obtained through the fibers surrounding the vessels. The cells of this tissue have closed ends and liquids in passing from one cell wall to another must be absorbed through the wall or some portion of it. Very likely the penetration takes place through the pits or through checks in the fiber walls (*33*). Hickory is a good example of a wood in which these wood fibers can be penetrated to a greater or less extent while in the oaks they cannot. Although the vessels of hickory are closed by tyloses as in the white oak, the wood fibers of hickory are much more permeable than the fibers in oak.

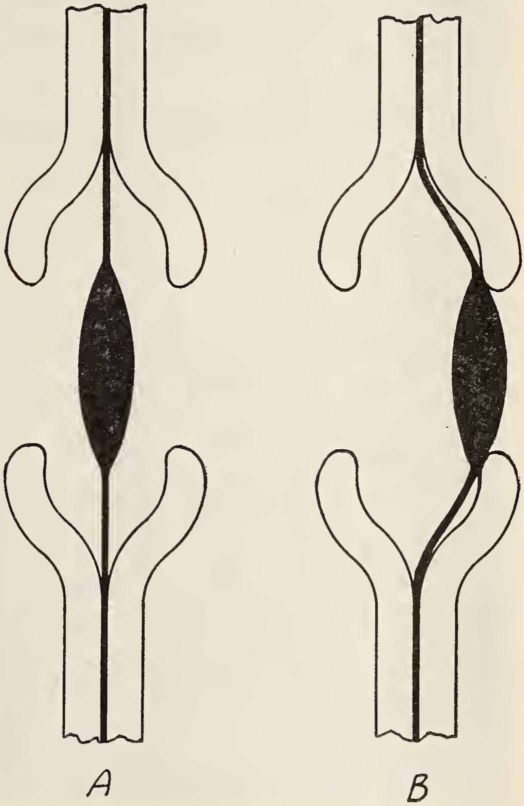

FIGURE 3.—Cross-sectional sketch of a bordered pit: *A*, Pit membrane centrally located; *B*, pit membrane permanently displaced.

BORDERED PITS AND SIMPLE PITS

A relatively unthickened portion of a cell wall where a thin membrane permits liquids to pass from one cell to another is called a pit. A bordered pit has an overarching rim which is not present in a

simple pit. Bordered pits are indicated by arrows marked *bp*, on figure 2. They are usually more or less circular and are partitioned by the pit membrane. The central portion of this membrane, which is thickened, is known as the torus. Figure 3 shows an enlarged cross-sectional drawing of a bordered pit and figure 4 shows both a face and profile view of bordered pits as seen through a microscope. At *A* in figure 3 and *a* in figure 4 the pit membrane is shown centrally

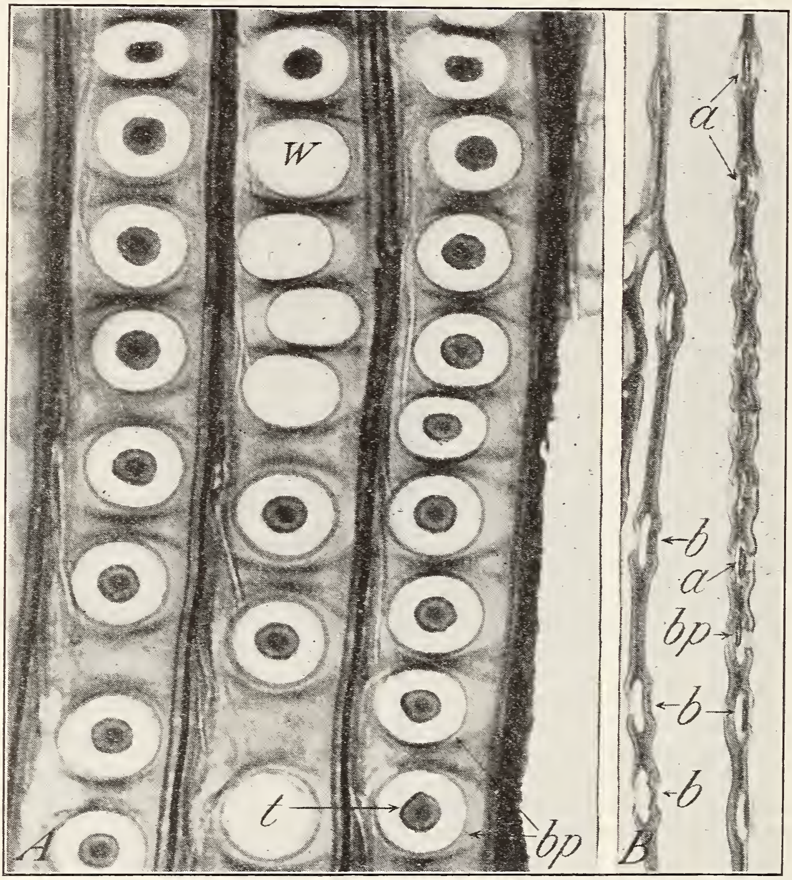

FIGURE 4.—Photograph taken through microscope showing greatly magnified bordered pits in longitudinal sections: *A*, Face view of bordered pits on cell wall: *t*, torus in bordered pit; *bp*, bordered pits; *w*, one of several white areas where section did not cut through torus. *B*, Profile view of bordered pits: *a*, tori centrally located; *b*, tori displaced; *bp*, bordered pits.

located. In many of the refractory woods, particularly in the heartwood, the membrane is often permanently displaced as indicated at *B* in figure 3 and *b* in figure 4. In this position they appear to retard or prevent the penetration of liquids. When the tori are not displaced t is probable that liquids pass from one tracheid to another through minute openings in the pit membrane.

In conifers the cells formed in the spring are relatively large with thin walls, while those formed later are smaller and have thicker walls. The wood in the annual ring composed of cells with thin walls is called spring wood and the portion containing the more dense wood is called

summer wood. In some hardwoods, for example the oaks, the spring wood is differentiated primarily by the larger pores which it contains. In others, such as maple and red gum, there is no marked distinction between spring wood and summer wood.

The summer wood of most of the conifers is more easily penetrated than the spring wood by both preservative oils and water solutions. The summer wood usually has more of the tori centrally located in the bordered pits than does the spring wood, and it is possible that this is one of the reasons for the better penetrations obtained in the summer-wood rings (*1*). Microscopical examinations of specimens that had proved very resistent to treatment in the summer wood showed a large portion of the summer-wood tori displaced (*4*, *5*, *28*). Since these microscopical studies have been made on only 5 or 6 species, much more work must be done to establish the relative importance of the position of the tori as a factor affecting penetration.

Simple pits are unthickened portions in the cell walls which are limited by a thin membrane without such thickening as a torus and which do not have an overhanging border. These pits are found in the wood parenchyma and ray cells of softwoods and hardwoods and in some of the fibers of the hardwoods. Little is known about their influence on penetration. In some of the hardwoods the simple pits may materially assist penetration when the vessels are closed by tyloses. They may also be of material assistance in distributing preservative through the wood from the open vessels.

RESIN PASSAGES

A number of the softwoods contain resin passages or ducts of indeterminate length. Resin passages are largest and most numerous in the pines. The longitudinal resin ducts are sometimes intersected by smaller radial resin passages within the wood rays which, particularly in a number of the pine species, assist in the penetration of liquids.

Species that contain resin passages to a greater or less degree are the pines, spruces, larches, tamarack, and Douglas fir. The other softwoods, which include the true firs, hemlock, cypress, redwood, cedar, and yew, do not normally have resin passages. In some of the woods like Engelmann spruce, white spruce, and tamarack, the resin passages are very small, comparatively scarce and open only for short distances. Species with resin ducts of this kind are usually resistant to treatment in the heartwood.

DENSITY

A comparison of the results obtained in the treatment of different species shows no correlation between the density or specific gravity of the wood and the penetration of preservatives. Some of the woods having high specific gravities, like the open-pored red oaks, are fairly easily penetrated and some, like white oak, are very resistant. Similarly some woods of low density, like ponderosa pine, are easy to penetrate and some, like corkbark fir, are very resistant to treatment. Other factors, such as the presence and condition of pores and resin ducts and the difference between heartwood and sapwood, have so much greater influence that if density has any effect at all it is completely obscured.

Within the same species, however, density may under certain conditions appear to have some influence on penetration in the softwoods. Timbers of the conifers having a large proportion of spring wood in comparison with the summer wood are of lower density and are usually more difficult to treat or take more erratic penetration than the denser timber of the same species. This is not really an effect of density, however, but of the difference in penetrability of spring wood and summer wood, which is very marked in many of the conifers. The important factor here is the percentage and distribution of summer wood which affects both the density and the penetrability. Differences in the relative penetrability of the summer wood and spring wood are not particularly noteworthy in the hardwoods.

Timbers of rapid growth often have both wide spring-wood and wide summer wood bands and the density of material of this kind may be as high as that of slower growth wood although the spring wood is much more conspicuous in the rapid growth. Frequently softwood timbers of rapid growth will show good penetration in the wide summer wood and little or no penetration in the wide spring-wood rings. The preservative in such timbers may follow the summer wood from the outside surface or may enter through checks or resin ducts and then penetrate the summer wood in a tangential direction. In most cases the less heavily treated spring wood is sufficiently protected by the adjacent covering of well-treated summer wood and by the preservative that may later diffuse into it from the summer wood.

Although density does not determine the penetrability of wood it does influence the maximum amount of preservative that may be absorbed in seasoned material. The preservative enters the air spaces in the wood, and when a large part of the air space is occupied no more preservative can enter. Although water and water solutions are absorbed by the cell walls as well as in the cell cavities, preservative oils are absorbed chiefly in the cavities and only to a slight extent in the cell walls. The denser the wood the less air space it contains and consequently the less preservative it can hold. Wood is seldom filled with preservative to complete saturation, however, since the various obstacles to penetration usually prevent complete penetration in timber of structural size. Some of the significant aspects of air space and density are discussed on page 17.

INFLUENCE OF STRUCTURE ON DIRECTION OF PENETRATION

Penetration may take place in wood in three directions, namely, longitudinally, which is in the direction of the length of the tree trunk; radially, which is in the direction of the radius of the tree; and tangentially or circumferentially, which is in the direction of the annual rings.

Practically all species are most easily penetrated longitudinally since liquids can follow in the direction of the vessels in the hardwoods and through the full length of the cellular space of the tracheids before passing through transverse cell walls in the softwoods. Liquids passing in a transverse direction, radial or tangential, must generally pass through many cell walls in moving a relatively short distance.

In some of the pines penetration is much better in the radial than in the tangential direction because it is assisted radially by the

resin ducts of the wood rays (fig. 5). In most of the other conifers, however, tangential penetration is usually better than the radial although in some resistant species the difference is slight. Various hardwood species, such as birch, maple, and elm, also appear to take better penetration in the tangential than in the radial direction. In many of the conifers tangential penetration is assisted by the fact that summer-wood bands are usually more permeable than either the wood rays or the alternate layers of spring wood. Radial penetration is largely prevented when both the wood rays and the spring-wood bands are resistant.

It might seem that transverse or side penetration into the faces of a sawed or hewed timber must depend entirely on the penetrability in a direction across the fibers or cell walls but this is not necessarily

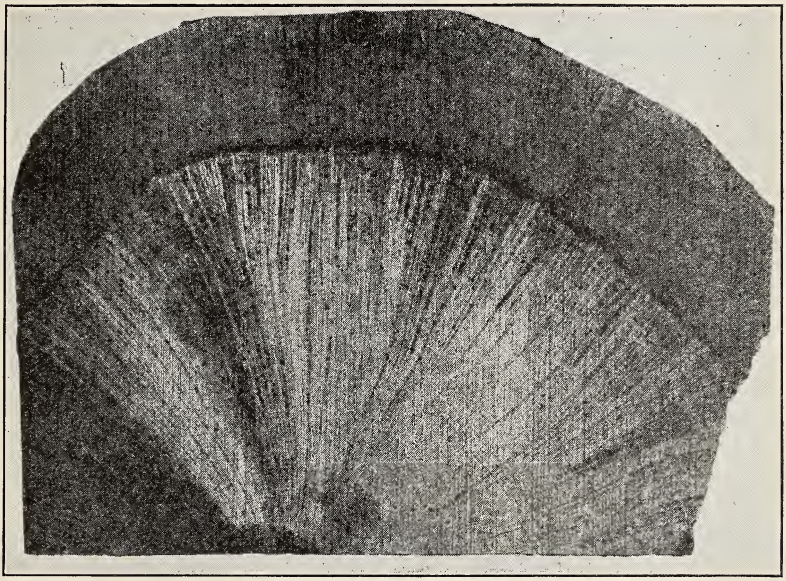

FIGURE 5.—Cross section of treated bristlecone pine; the dark, radial streaks in the heartwood show that the penetration of the preservative was assisted by the wood rays.

the case. A certain amount of penetration in the direction of the fibers or vessels (longitudinal penetration) is obtained on practically all sawed or hewed surfaces since many of the vessels of the hardwoods or tracheids of the softwoods lie at an angle with the cut faces, and help conduct liquids to varying depths. When the angle made by the fibers is large, such as in timbers having a marked cross-grained structure, penetration is usually deeper than in timbers that are fairly straight-grained.

Variability in penetration at different points along the surface of a sawed timber is apparently influenced to a considerable extent by the number of cells that assist in longitudinal penetration from the side surfaces. It is natural that at some points most of the vessels or tracheids may lie nearly parallel with the surface while at other points a variable number will lie at an angle with it. Even longitudinal penetration is slight in the heartwood of some of the more

resistant species, such as mountain type Douglas fir and red gum, and it is practically impossible to obtain appreciable penetrations in the radial and tangential directions in the heartwood of such species.

CLASSIFICATION OF SPECIES WITH RESPECT TO PENETRABILITY

It is impossible to arrange the different species in exact order of their relative resistance to penetration by wood preservatives because of the many variables that must be considered. The following rough classification, however, should be helpful: (1) Heartwood easily treated, (2) heartwood moderately difficult to treat, (3) heartwood difficult to treat, and (4) heartwood very difficult to treat. This grouping is based both on the results of laboratory experiments and on observations made under commercial-treating conditions. Though it is recognized that there may be a considerable variation in the penetrability of the heartwood of species within the same group, nevertheless if the classification is taken as a whole there is a definite difference in the relative resistance to treatment of the woods in one group as compared with those in another.

GROUP 1, HEARTWOOD EASILY PENETRATED

SOFTWOODS	HARDWOODS
Bristlecone pine (*Pinus aristata*)	Basswood (*Tilia glabra*)
Piñon (*Pinus edulis*)	Beech (white heartwood) (*Fagus grandifolia*)
Ponderosa pine (*Pinus ponderosa*)	Black gum (*Nyssa sylvatica*)
	Green ash (*Fraxinus pennsylvanica lanceolata*)
	Pin cherry (*Prunus pennsylvanica*)
	River birch (*Betula nigra*)
	Red oaks (*Quercus* spp.)
	Slippery elm (*Ulmus fulva*)
	Sweet birch (*Betula lenta*)
	Tupelo gum (*Nyssa aquatica*)
	White ash (*Fraxinus americana*)

GROUP 2, HEARTWOOD MODERATELY DIFFICULT TO PENETRATE

SOFTWOODS	HARDWOODS
Douglas fir (coast) (*Pseudotsuga taxifolia*)	Black willow (*Salix nigra*)
Jack pine (*Pinus banksiana*)	Chestnut oak (*Quercus montana*)
Loblolly pine (*Pinus taeda*)	Cottonwood (*Populus* sp.)
Longleaf pine (*Pinus palustris*)	Largetooth aspen (*Populus grandidentata*)
Norway pine (*Pinus resinosa*)	Mockernut hickory (*Hicoria alba*)
Shortleaf pine (*Pinus echinata*)	Silver maple (*Acer saccharinum*)
Western hemlock (*Tsuga heterophylla*)	Sugar maple (*Acer saccharum*)
	Yellow birch (*Betula lutea*)

GROUP 3. HEARTWOOD DIFFICULT TO PENETRATE

SOFTWOODS	HARDWOODS
Eastern hemlock (*Tsuga canadensis*)	Hackberry (*Celtis occidentalis*)
Engelmann spruce (*Picea engelmannii*)	Rock elm (*Ulmus racemosa*)
Lowland white fir (*Abies grandis*)	Sycamore (*Platanus occidentalis*)
Lodgepole pine (*Pinus contorta*)	
Noble fir (*Abies nobilis*)	
Sitka spruce (*Picea sitchensis*)	
Western larch (*Larix occidentalis*)	
White fir (*Abies concolor*)	
White spruce (*Picea glauca*)	

GROUP 4. HEARTWOOD VERY DIFFICULT TO PENETRATE

SOFTWOODS

Alpine fir (*Abies lasiocarpa*)
Corkbark fir (*Abies arizonica*)
Douglas fir (mountain) (*Pseudotsuga taxifolia*)
Northern white cedar (*Thuja occidentalis*)
Tamarack (*Larix laricina*)
Western red cedar (*Thuja plicata*)

HARDWOODS

Black locust (*Robinia pseudoacacia*)
Beech (red heartwood) (*Fagus grandifolia*)
Chestnut (*Castanea dentata*)
Red gum (*Liquidambar styraciflua*)
White oaks (*Quercus* spp.)

The sapwood of most of the species in the different groups is, in general, not difficult to impregnate under pressure but eastern hemlock, the true firs, and the spruces have sapwood that is nearly as resistant as their heartwood. The sapwood of the last-named woods is usually also very difficult to distinguish from the heartwood. While the sapwood of the other species is not particularly difficult to treat under pressure there is, nevertheless, a considerable variation in the relative ease with which the sapwood of some species takes treatment in comparison with that of other species.

In treating-plant operation easily treated woods and very resistant woods should not be included in the same charge. The easily treated material under such conditions would absorb more than the average and the resistant material less than the average amount of preservative per unit volume calculated for the charge. Differences in average absorption between the two groups might be several hundred percent.

In round material, such as poles, posts, and piling, only the treatability of the sapwood ordinarily needs to be considered because the heartwood is so deeply covered with sapwood that it is not expected to be penetrated except at end surfaces. In ties, or other sawed material, there is sometimes much sapwood and also considerable heartwood area exposed. In such material the treating-plant operator cannot avoid having easily treated and resistant wood in the same charge. It is not enough in treating such material merely to get some specified absorption because the preservative may be absorbed almost entirely by the sapwood, leaving the heartwood with little protection. The operator should assure himself that as much penetration as possible is obtained in the heartwood faces and all his technical skill may be called into play to bring this about. The empty-cell processes are particularly useful in the treatment of such material as they permit a larger gross absorption for a given net retention than is possible when the full-cell method is employed.

MOISTURE CONTENT, SPECIFIC GRAVITY, AND AIR SPACE IN WOOD

The material wood contains wood substance, moisture, and air or gas. The wood substance includes both the cellular structure and extractives of the wood and usually has a variable quantity of water absorbed in the cell walls. When wood is green or wet the water also occupies a part or all of the cell cavities. In addition there is usually more or less air or gas in the wood cells, depending on the density of the wood and the moisture content. In the present discussion the volume occupied by air or gas is designated as air space.

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SHRINKAGE DURING SEASONING

Water in the cell cavities is commonly called free water. The fiber-saturation point is known as the point at which only the cell walls are saturated and no free water is present. This point is not determined with exactness and varies for the different species but is usually at a moisture content between 25 and 35 percent. For practical purposes it is sufficient to assume the average as about 25 percent. After the wood has dried to the fiber-saturation point further seasoning causes the wood to shrink, the amount of shrinkage depending on the amount of seasoning and upon the species. In wood dried slowly and uniformly so that the inside dries as rapidly as the outside there should be theoretically no shrinkage above an average moisture content corresponding to the fiber-saturation point. Such uniform seasoning is impossible to attain in commercial practice, however, and in air-seasoning timbers the outer part begins to shrink before the inside gets down to the fiber-saturation point. This shrinkage of the surface layers around a core that has not begun to shrink favors checking. Most of the shrinkage occurs in the radial and tangential directions and is nearly twice as great tangentially as radially. The shrinkage in the longitudinal direction is negligible. The shrinkage in volume from a green to an air-dry condition is usually about 6 to 9 percent for the hardwoods and 4 to 7 percent for the softwoods. The shrinkage in volume from a green to an oven-dry condition is about twice as much as that to an air-dry condition.

Formulas for computing the relation of moisture content, specific gravity, shrinkage, and air space in wood are given on page 112.

MOISTURE CONTENT

It is standard practice to base the moisture content on the weight of the oven-dry wood.[7] This method has the advantage that the oven-dry weight can be obtained at any time and affords a constant base. Furthermore, with this base the moisture percentage shows directly the number of parts of water by weight to the number of parts of oven-dry wood by weight.

Frequently it is inconvenient to make direct moisture determinations from timbers that are seasoning. In this event a rough estimate of the average moisture content can be made by weighing representative timbers and then consulting figure 6. The weighing should be done when the moisture content of most of the material is at or above the fiber-saturation point, at which time little if any shrinkage has taken place. In figure 6 the fiber-saturation point has been assumed as 25 percent, which is sufficiently accurate for practical purposes, and the specific-gravity values are the averages for the species.

Figure 6 can also be used for other woods than those listed in the legend by interpolating for the given specific gravity. The maximum weight line indicates the maximum weight the wood can have for the specific gravity indicated when no air space is present and the cell cavities are filled with water.

In estimating the average moisture content from the weight of the wood it should be borne in mind that knots, variations in specific gravity for different timbers, and the like, influence the results and the moisture indicated will be only an approximate value.

[7] Wood is oven-dried by heating a sample at approximately 100° C. (212° F.) until the weight remains constant.

EXAMPLE OF THE USE OF FIGURE 6

Assume the wood under consideration is longleaf pine weighing 60 pounds per cubic foot and is still above the fiber-saturation point. What is its moisture content?

Figure 6 shows that longleaf pine has an average specific gravity of 0.54, based on green volume. Starting at the scale to the left, follow a horizontal line representing the weight of the wood under consideration, which in this example is 60 pounds per cubic foot, until it intersects a diagonal line representing the average specific gravity of the species, which in this example is 0.54. The desired moisture-content value is then read on the bottom horizontal scale directly below the intersection point, which in this example is 78 percent.

RELATION OF MOISTURE CONTENT TO AMOUNT OF WATER IN WOOD

It is evident that two woods having the same percentage of moisture but different specific gravities will have different amounts of water per unit volume. Figure 7 shows the weight of water per cubic foot

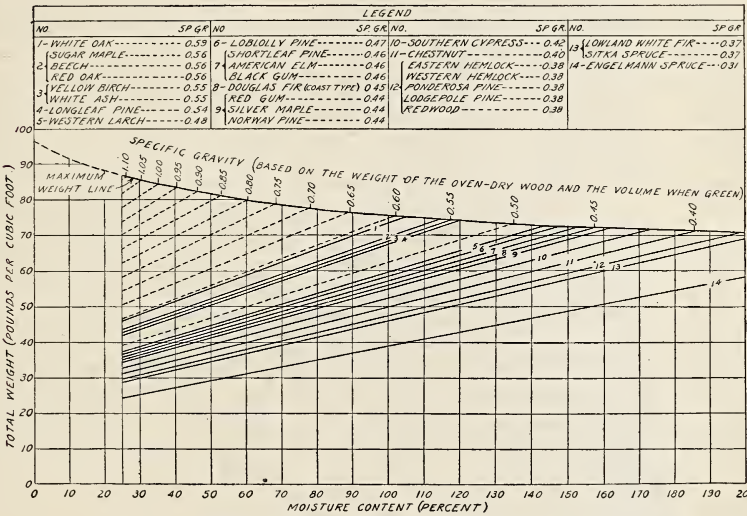

FIGURE 6.—Relation between weight of green wood and moisture content.

for wood having a given specific gravity and moisture content. The line slanting downward from left to right shows the maximum weight of water per cubic foot and the corresponding maximum moisture content for wood having any particular specific gravity. Since it would probably be impossible to fill all the air space with water the theoretical maximum moisture content cannot be attained although in some woods it may be closely approached.

EXAMPLE OF THE USE OF FIGURE 7

The specific gravity is 0.45 based on the weight of the oven-dry wood and volume when green. What is the maximum amount of water the wood can hold per cubic foot?

Starting with a specific gravity value of 0.45 on the horizontal scale at the bottom of figure 7, follow vertically to the intersection with the line slanting downward from left to right. This intersection indicates that the maximum moisture content of the wood is about 158 percent. For this same intersection point the vertical scale on the left shows that the maximum amount of water the wood can hold is 44 pounds per cubic foot.

SPECIFIC GRAVITY

The specific gravity of wood is commonly understood as the ratio of the weight of the oven-dry wood based on the volume at the current moisture content, to an equal volume of water at maximum density.

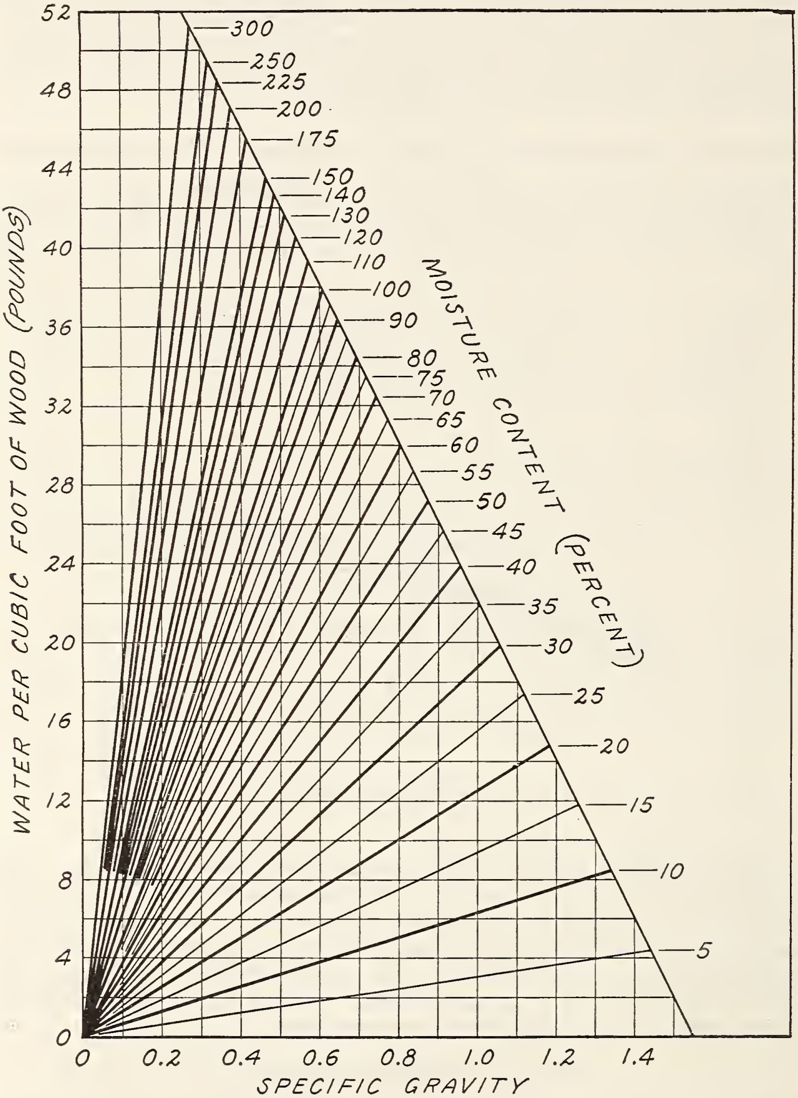

FIGURE 7.—Relations between weight of water in wood, specific gravity, and percentage of moisture.

At the fiber-saturation point wood is at its maximum volume and the specific gravity will not change when more water is absorbed. Below the fiber-saturation point the specific gravity changes for each change in moisture content, increasing as the moisture content decreases. This change in specific gravity is because of the increase in the amount of wood substance per unit volume as the wood shrinks. The maxi-

mum specific gravity will therefore be that based on the weight of the oven-dry wood and the volume when oven-dry. Likewise the minimum specific gravity will be that based on the oven-dry weight of the wood and the volume when green or when the wood is at or above the fiber-saturation point.

While changes in specific gravity normally occur because of shrinkage as the moisture is reduced below the fiber-saturation point, there is a condition known as collapse which sometimes occurs during seasoning or when the wood is subjected to treating pressures that are too high. As the term "collapse" suggests, the cell walls are more or less broken down, thus causing a decrease in the amount of air space in the lumena or cell cavities. This condition tends to increase the amount of wood substance per unit volume and consequently increases the specific gravity.

In the metric system the specific gravity will be the weight of the oven-dry wood in grams per cubic centimeter. If the volume is measured in cubic inches the specific gravity will be the weight of the oven-dry wood per cubic inch divided by 0.0361, the weight in pounds of 1 cubic inch of water at maximum density. If the volume is measured in cubic feet the specific gravity will be the weight in pounds of the oven-dry wood per cubic foot divided by 62.4, the weight of a cubic foot of water at maximum density. The resulting figures for specific gravity will be the same regardless of whether the metric or English system of measurements is used.

For practical purposes the specific gravity, based on the weight of the oven-dry wood and volume at current moisture content, of any species may be assumed to increase in direct proportion to the loss of moisture below the fiber-saturation point. The range will then be between the specific gravity based on the weight of the oven-dry wood and the volume when green and that based on the weight of the oven-dry wood and the volume when oven-dry. From this relation the specific gravity at a moisture content below the fiber-saturation point can be determined from the following equation:

$$S_k=\left[S_d-(S_d-S_g)\frac{K}{25}\right]$$

where S_k is the specific gravity at the moisture content K, S_d is the specific gravity based on the weight and volume when oven-dry; S_g is the specific gravity based on the weight when oven-dry and volume when green, and K is a moisture content below the fiber-saturation point. In this equation the fiber-saturation point is taken as 25 percent.

In making computations involving specific-gravity values it must be understood that the specific gravity is independent of the amount of water in the wood except as the presence of the water affects the volume or, in other words, the shrinking and swelling. The specific-gravity values employed in the figures and formulas of this publication are therefore based on the weight of the oven-dry wood and the volume at the current moisture content.

The specific gravity designated throughout this publication by the letter S must not be confused with the specific gravity of wood substance; that is, the specific gravity of the oven-dry wood if it contained no air space. The specific gravity of wood substance has

been found to be fairly constant for all species and a value of 1.55 has been used for computations in which this specific gravity enters into the formulas.

EXAMPLE OF THE USE OF THE SPECIFIC-GRAVITY EQUATION

What is the average specific gravity of red oak at 12 percent moisture? For the equation

$$S_k=\left[S_d-(S_d-S_g)\frac{K}{25}\right]$$

the average values of S_d and S_g for red oak are given in table 1 as 0.66 and 0.56, respectively. Then S_{12}, the specific gravity at 12 percent moisture content equals

$$\left[0.66-(0.66-0.56)\frac{12}{25}\right]$$

or 0.61 approximately.

TABLE 1.—*Average moisture content for green heartwood and sapwood and specific gravity values for 26 species*

Species	Trees tested	Average moisture content		Specific gravity [1]	
		Heartwood	Sapwood	Based on volume when green and weight when oven-dry	Based on volume and weight when oven-dry
	Number	*Percent*	*Percent*		
Hardwoods:					
Ash, white	12	38	40	0.55	0.64
Beech	6	53	78	.56	.67
Birch, yellow	9	68	71	.55	.66
Chestnut	2	120		.40	.45
Elm, American	3	95	92	.46	.55
Gum, black	4	50	61	.46	.55
Gum, red	2	79	137	.44	.53
Maple, silver	4	60	88	.44	.51
Maple, sugar	6	58	67	.56	.68
Oak, red (commercial)	5	85		.56	.66
Oak, white (commercial)	3	68		.59	.71
Softwoods:					
Cypress (southern)	2	120	171	.42	.48
Douglas fir	5	36	117	.45	.51
Fir, lowland white	3	91	136	.37	.42
Hemlock, eastern	5	58	119	.38	.43
Hemlock, western	13	42	170	.38	.44
Larch, western	2	54	124	.48	.59
Pine, loblolly	23	36	96	.47	.54
Pine, lodgepole	5	36	113	.38	.43
Pine, longleaf	31	34	99	.54	.62
Pine, Norway	4	31	135	.44	.51
Pine, ponderosa	4	40	148	.38	.42
Pine, shortleaf	8	34	108	.46	.54
Redwood	43	100	210	.38	.42
Spruce, Engelmann	2	54	167	.31	.35
Spruce, Sitka	2	33	146	.37	.42

[1] Specific-gravity values are based on data from the following: MARKWARDT, L. J., and WILSON, T. R. C., STRENGTH AND RELATED PROPERTIES OF WOODS GROWN IN THE UNITED STATES. Tech. Bull. 479. They are not confined to the number of trees tested as listed in this table.

AIR SPACE IN WOOD

A knowledge of the amount of air space in wood is useful in estimating the maximum amount of unoccupied space that can be filled with preservative under the moisture conditions at which it is treated.

Figure 8 is constructed so that the percentage of air space can be readily determined for any wood having a moisture content M and a specific gravity S based on the volume at that moisture content.

EXAMPLES OF THE USE OF FIGURE 8

The following conditions are assumed: Material, loblolly pine piling conditioned by the steaming-and-vacuum process; amount of sapwood based on the

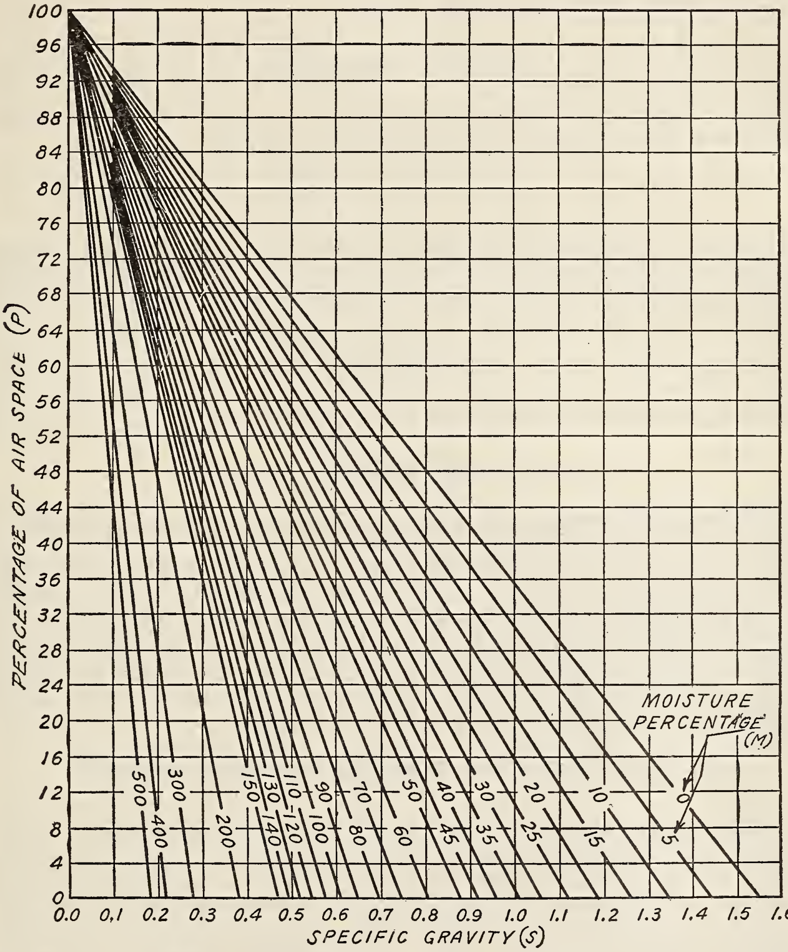

FIGURE 8.—Maximum percentage of air space in a given volume of wood having a moisture content M and specific gravity S.

total volume of timber, 85 percent; average moisture content of the sapwood at the time of treatment, 60 percent; average specific gravity of the wood based on weight of the oven-dry wood and volume when green, 0.47; specific gravity of the creosote at the temperature employed during the pressure treatment, 1.02; method of treatment, full-cell process; only the sapwood is impregnated and 90 percent of the total air space is left filled after treatment. What is the maximum absorption of preservative in pounds per cubic foot?

The maximum absorption in pounds per cubic foot if all the air space were filled is equal to the available air space per unit volume times 62.4 times 1.02. From figure 8 it is found for a specific gravity of 0.47 and moisture content of

60 percent that the available air space amounts to about 41 percent but since only 85 percent of the total volume is to be impregnated the available air space per unit volume is (0.41×0.85) or approximately 35 percent. The absorption is then ($1.02 \times 62.4 \times 0.35 \times 0.90$) or about 20 pounds per cubic foot of total volume.

As another example, assume that sap loblolly pine timbers, which can be completely penetrated, have been seasoned to 15-percent moisture content and are to be impregnated with a water solution. What is the maximum absorption of preservative solution in pounds per cubic foot?

The values of S_d and S_g for the equation

$$S_k = \left[S_d - (S_d - S_g)\frac{K}{25} \right]$$

are given in table 1 for loblolly pine as 0.54 and 0.47, respectively. The specific gravity at 15 percent moisture content would therefore be

$$\left[0.54 - (0.54 - 0.47)\frac{15}{25} \right]$$

or about 0.50. For this specific gravity and 15-percent moisture, figure 8 shows that the wood has about 60 percent of air space. From figure 7, for a specific gravity of 50 and a moisture content of 15 percent, the amount of water is found to be about 4.7 pounds per cubic foot. From the equation

$$P_s = 100\left[\frac{S_k - S_g}{S_k} \right]$$

the increase in volume when the wood is wet will be

$$100\left[\frac{0.50 - 0.47}{0.50} \right]$$

or roughly 6 percent.

The amount of the original water per cubic foot after treatment would then be $\frac{4.7}{1.06}$, or about 4.4 pounds. Since the wood has a specific gravity of 0.47 when wet or green, figure 7 shows that with all the air space filled the maximum amount of water the wood could hold would be about 44 pounds per cubic foot. The maximum weight of preservative solution that the wood could hold is $44 - 4.4$ or 39.6 pounds if the specific gravity of the solution were 1 or the same as that of water. Assuming 90 percent of the air space can be filled and that the specific gravity of the preservative solution is 1.03, the possible absorption of solution would be $1.03 \times 0.90 \times 39.6 = 36.7$ pounds per cubic foot.

PREPARATION OF TIMBER FOR TREATMENT

Much of the success of treating operations depends upon the preparation of the timber to receive the preservative. Timbers of practically all species require more or less seasoning or conditioning before they can be satisfactorily impregnated. Air seasoning is the method most generally employed but for various reasons, such as unfavorable climatic conditions, rush orders, or restricted storage space, it is often necessary to use the artificial methods of steaming and vacuum or boiling in oil under vacuum in order to condition the wood for treatment.

AIR SEASONING

Some of the more important considerations in air seasoning include species and size of timber, proportion of sapwood, time of cutting, peeling, climatic conditions, locality in which the timber is seasoned, and method of piling.

SPECIES AND SIZE OF TIMBER

Even under the same conditions, timbers of similar size but of different species often vary considerably in the time required for air seasoning. This is partly on account of wide variations in the original moisture content of the wood and partly because various woods differ greatly in the rate at which they give off moisture. Table 1 shows average moisture-content values for green heartwood and sapwood of many of the species commonly treated. The values given in the table are averages for a varying number of trees of each species. Individual timbers of a given species, or material obtained from a given locality, may differ to a greater or less extent from the averages given.

It may be noted from table 1 that the softwoods usually show a much higher moisture content in the sapwood than in the heartwood and that this difference is less marked in the hardwoods.

Large timbers season more slowly than those of small dimensions because of the greater volume of wood in proportion to the surface area and because the moisture at the interior must travel a greater distance through the wood to reach the surface. It is advisable to season large timbers slowly in order to avoid excessive damage from checking. Large timbers have a higher average moisture content after a given period of air seasoning than timbers of smaller sizes, although the outer inch or two of the larger timbers may be practically as dry as the smaller material.

SEASONING OF HEARTWOOD AND SAPWOOD

The sapwood of most species seasons at a much faster rate than the heartwood. On the other hand, the sapwood often contains a higher percentage of moisture than the heartwood and this tends to offset its greater seasoning rate. In round timbers or sawed material in which the heartwood is surrounded by sapwood the faster seasoning rate of the sapwood may encourage checking. Furthermore, the sapwood is on the outside of the piece and, except at end surfaces, begins to season sooner than the heartwood. As a result, the sapwood dries and begins to shrink while the heartwood still retains its original size. Checking of the sapwood is inevitable in such cases and the checks later may extend into the heartwood as it dries. The size and severity of the checks can be limited to a considerable extent, however, by controlling the drying rate through piling methods and by the use of end coatings. In material that is all sapwood there is less danger of checking than in all heartwood material.

Since sapwood has low resistance to decay, it should be seasoned with as little delay as possible and under the most favorable drying conditions. Rapid seasoning requires conditions contrary to those that favor reduced checking. The danger of infection and the danger of checking vary considerably with locality and species, however, so that each operator must work out as best he can the seasoning methods most suitable for his species and locality.

COATINGS USED TO REDUCE END CHECKING

Since wood dries more rapidly from the end than from the side grain, end checking is a problem in the seasoning of some timbers. Under such conditions the application of moisture-resistant end coatings is very helpful.

Two classes of coatings are commonly used for such purposes. The coatings in the first class are liquid at ordinary temperatures and do not require heating before application while the second are solid at ordinary temperatures and must be heated before application. In order to obtain an effective covering a thick coating should be applied over the entire end surface. Cold coatings should have a consistency that will prevent appreciable dripping from the surface.

The best cold coatings developed at the Forest Products Laboratory are (1) hardened gloss oil thickened with barites and asbestine (fibrous talc) and (2) highgrade spar varnish and barites. The first is fairly cheap; the latter more expensive.

The hardened gloss-oil coating is made as follows: The oil is composed of approximately 8 parts by weight quicklime, 100 parts rosin, and 57 parts spirits such as naphtha or turpentine. To 100 parts of the gloss oil add 25 parts barites and 25 parts of asbestine. The asbestine helps prevent the pigment from settling out. Any paint manufacturer can prepare this coating or it can be mixed by the user as needed if a thick grade of gloss oil is obtained. Since some of the gloss oils on the market have little moisture resistance it is important that the coating be made up in accordance with the foregoing formula.

A heavy coat of paraffin is also effective in reducing end checking if the coating is not exposed to temperatures that will cause it to melt off the surface.

PEELING

All material should be peeled before seasoning because bark retards the drying of the wood, harbors insects, and favors decay infection in the sapwood. The peeling should be thoroughly done, even to the removal of the inner bark. The inner bark of many species, particularly the conifers, is highly impervious to liquids, and if strips of appreciable size are left on the wood they may not only interfere with seasoning but also subsequently prevent the penetration of preservatives.

As a rule, timber cut during the active growing months from May to July peels more easily than that cut at other season of the year. It has been found at the Forest Products Laboratory that the peeling of timbers cut in fall and winter can be facilitated by boiling or steaming them from 1 to 3 hours.

TIME OF CUTTING

The most favorable time for cutting timber from the standpoint of preventing damage while awaiting treatment is in the late fall or winter, although with proper care most kinds of wood can be seasoned satisfactorily for treatment if cut at any time during the year. Round timbers peel much easier, however, when cut in spring or early summer. In cold weather wood seasons more slowly and there is less danger of severe checking than in warm, dry weather. Insects and decay are inactive during cold weather and hence there is less danger of winter-cut wood becoming infected. By the time warm weather causes the revival of insect and fungous activity the timber is usually out of the woods and partly seasoned so that its resistance to infection is increased.

The advantage from winter cutting depends partly upon the climatic conditions and partly upon the susceptibility of the wood to damage. Greatest care is required in the southern States where the winter is short and not very cold and where many of the species of wood cut for ties and poles have a large percentage of sapwood and are very susceptible to insect and fungous damage. Winter cutting is best in the southern States the same as in colder climates but the necessity of prompt removal from the woods to proper seasoning yards is greater than where long, cold winters prevail. This holds both for ties, piling, and poles that are manufactured in the woods and for logs that are later to be sawed into lumber, ties, or timbers.

It is commonly believed that there is less sap in the trees in winter than in summer but experiments do not substantiate this belief. Experiments made both in the United States (*12*) and in Europe show that trees cut in winter have fully as much sap in them as trees cut in the spring or summer.

CLIMATIC CONDITIONS AND LOCALITY

Climatic conditions influence air seasoning. In parts of the South where the rainfall is considerable and the temperature and humidity are relatively high throughout a large part of the year, it is difficult and sometimes practically impossible thoroughly to air season ties and round timbers of certain species before serious injury occurs from decay. This difficulty is experienced particularly with material that is largely sapwood or is low in decay resistance. When timber must be air seasoned under such unfavorable conditions it is essential that every precaution be taken to regulate the controllable factors so that the most desirable seasoning conditions will be provided. Some attempts have been made to develop inexpensive pretreatments with chemicals that will temporarily prevent decay and safely allow a longer seasoning period. Satisfactory methods of this kind may yet be developed.

Infection by decay may be deferred for many months by giving poles a light empty-cell treatment with creosote when green or after partial seasoning and then returning them to the yard for further seasoning or for storage while waiting for treating orders.

In dry or arid regions decay infection is seldom ecountered during seasoning except under the most careless handling. In such regions severe checking caused by too rapid drying may be the most important factor and the methods of handling and piling should be selected accordingly.

DRAINAGE AND METHOD OF PILING

Much of the annual loss of ties, poles, and timbers ruined or damaged while seasoning or in storage could be prevented through improvement in piling methods. The seasoning yard should be located on dry, well-drained ground where there is good air circulation. Low or filled ground favors the retention of water in the soil and if surrounded by higher ground may act like a pocket for the collection of damp air and fog. The location of wood-preserving plants is determined most often by shipping facilities, cost of land, and the like, rather than the advantages of the site for seasoning. Under such

conditions the plant operator must make the best of that which is available.

Good pile foundations are essential for efficient air-seasoning. They should be of treated wood, or some other material that does not decay. It is bad practice to place the bottom course of timber directly on the ground because it does not season well and, in most localities, is almost sure to become infected with decay. Well-treated reject ties and timbers make excellent foundation material. The foundations should be high enough to keep the bottom course of timbers well off the ground. A clearance of 1½ to 2 feet should be allowed because air circulates downward through a seasoning pile and the moisture-laden air must have freedom to flow out at the bottom. The seasoning piles should be built openly and far enough from each other to allow free circulation.

The foregoing precautions are especially necessary where there is severe danger of decay infection. In extremely dry or arid regions, however, the precautions should be modified by making the piles tighter and the spacing closer in order to prevent too rapid drying and excessive checking. Every treating-plant operator should study his own conditions thoroughly, select the methods best adapted to these conditions, and keep constantly on the alert for improvements.

SANITATION

The seasoning yard should be kept clean and free from holes where water, waste wood, or debris of any kind may accumulate. Weeds and brush should be kept down not only within the yard but around it. Neglect in these respects retards seasoning, favors decay, and increases the fire hazard.

LENGTH OF SEASONING PERIOD

Table 2 gives the air-seasoning periods employed by wood-preserving plants in various parts of the United States for timbers of different species. The periods are for ties, poles, and piling, since such timbers comprise the greater proportion of the material air-seasoned for treatment. The seasoning periods used for lumber, bridge timbers, and similar material are more variable than for ties, poles, and piling on account of the greater differences in cross-sectional dimensions. Table 2 gives the current practice (1930–31), which was not necessarily best practice. The lack of uniformity is indicative of the variety of opinion among plant operators as to the amount of seasoning desirable, differences in details of yard location and piling methods, and differences in treating methods and in purchasers' requirements.

TABLE 2.—*Air-seasoning periods employed by individual wood-preserving plants in different parts of the United States for ties, piling, and poles of various species, 1930–31*

Species	Form of timber	Region in which plants are located [1]	Seasoning period
			Months
Beech	Ties	Interior eastern	6
Do	do	do	8–12
Do	do	Atlantic	6–8
Cottonwood	do	Interior western	12
Douglas fir (mountain)	do	do	9–12
Do	do	do	6
Do	do	do	1–1½
Do	do	do	[2] 3
Douglas fir (coast)	do	do	10–12
Do	do	do	6–7
Do	do	do	3
Do	do	Pacific	10–12
Do	do	do	6–12
Do	do	do	3–12
Do	Piling	do	12
Eastern hemlock	Ties	Interior eastern	8–12
Engelmann spruce	do	Interior western	6–8
Do	do	do	8–10
Do	do	do	[2] 3
Gum	do	Southern	3–4
Do	do	do	4–6
Do	do	do	10–12
Do	do	Interior eastern	8–12
Lodgepole pine	do	Interior western	8–12
Do	do	do	3–6
Maple	do	Interior eastern	6
Do	do	do	8–12
Do	do	Atlantic	6–8
Ponderosa pine	do	Interior western	3–6
Do	do	do	8–12
Red oak	do	Interior eastern	12
Do	do	do	10–14
Do	do	do	8–12
Do	do	do	12–14
Do	do	do	14–18
Do	do	Interior western	6
Do	do	Southern	10–12
Do	do	Interior eastern	10–12
Do	do	do	8–12
Do	do	Southern	10–13
Do	do	do	12–13
Do	do	do	12–14
Do	do	do	15–16
Southern yellow pine	do	do	2
Do	do	do	2–3
Do	do	do	3–4
Do	do	do	3–5
Do	do	do	5–6
Do	do	Interior eastern	5–6
Do	Poles and piling	Southern	2–3
Do	do	do	3–4
Do	Ties	Atlantic	5–6
Western hemlock	do	Interior western	12
Do	do	do	6
Western larch	do	do	9–12
White oak	do	Interior eastern	14–18
Do	do	Atlantic	12–14
Do	do	do	10–12
Yellow birch	do	Interior eastern	6
Do	do	do	8–12
Do	do	Atlantic	6–8

[1] The Atlantic region comprises Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Delaware, West Virginia, and Virginia. The southern region comprises Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Florida, Arkansas, Louisiana, Oklahoma, and Texas. The interior eastern region comprises Michigan, Ohio, Indiana, Illinois, Wisconsin, Minnesota, Iowa, Missouri, and the eastern part of North Dakota, South Dakota, Nebraska, and Kansas. The interior western region comprises Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, and the western part of North Dakota, South Dakota, Nebraska, and Kansas. The Pacific region comprises Washington, Oregon, and California.
[2] Partly seasoned in woods.

There is apparently a limit to the amount of water that should be removed from wood if the best results are to be obtained in treatment. Timbers that have been seasoned too long, or perhaps too rapidly, sometimes seem to develop an increased resistance to penetration

at the surface which is commonly called "casehardening." A better term might be "surface hardening", since casehardening is the name applied in kiln drying or air drying when internal stresses are set up in which the inner layers of the wood are in tension and the outer layers are in compression. The optimum degree of seasoning for treatment is not known for any species. There is room for a great deal of fruitful study in developing the relations between the character and degree of seasoning and the treatability of the wood with different preservatives and processes.

CONDITIONING BY THE STEAMING AND VACUUM PROCESS

Frequently timber must be treated without waiting for it to air-season. When green material is to be treated it is customary to condition the wood by an artificial heat treatment so that it can be penetrated with the preservative. The principal conditioning method used with green southern pine timber is the steaming-and-vacuum process in which the timber is first steamed and then a vaccum applied. Although this process does not remove enough water from the wood so that the wood may be considered as seasoned, it does remove appreciable amounts of water from green material and in addition, in a manner not fully understood, makes the wood much more penetrable by preservatives.

The steaming process was formerly used for various species but is now most commonly used in the Southern States for the treatment of green southern yellow pine. Table 3 summarizes the results of a survey of steaming-and-vacuum conditions employed at various treating plants in the South in 1930 and 1931. The steaming-and-vacuum treatment was formerly practiced much more extensively than at present and more severe steaming conditions were employed.

Table 3.—*Steam-and-vacuum treatments employed at various plants treating green southern pine, 1930–31*

Plant No.	Material	Steam pressure	Steam period [1]	Vacuum period after steaming
		Pounds per square inch	*Hours*	*Hours*
1	Poles and piling	30	8–10	2
	Sawed timber	30	7–10	2
2	Poles	27	7–10	3
	Piling	27	8–12	3
3	Poles	20	8	3
4	Poles and piling	20	7	1
	Cross arms	15	5	1
5	Poles and piling	30	10–12	2
	Sawed timber	30	10–12	2
	Cross arms	20–30	8	2
6	Poles and piling	20–30	8–12	2–2½
7	do	20–40	6–14	3–4
8	Poles	35–40	8	3–4
	Piling	30–50	12–15	6
9	Poles and piling	20–30	12–14	4
10	do	15–20	8–10	3–4
11	do	20	12–14	2–2½
12	do	20	6–12	1
	Sawed timber	20	4–12	1
13	Poles and piling	20	6–8	2
14	do	25–30	6–10	4
	Sawed timber	25–30	8–10	3–4
15	Poles and piling	25–30	8–10	2
	Cross arms	25–30	5	1
16	Poles	20–25	8–19	1
17	Poles and piling	30	6–16	3–4
	Sawed timber	30	6–10	2–3
18	Poles and piling	25–30	8–14	2
	Sawed timber	25–30	8–10	2
19	Poles and piling	20	6–12	2
	Sawed timber	20	8–10	2
	Ties	20	4	1–1½
	Wood conduit	15	5	2
20	Poles and piling	20–30	10–12	3–4
	Sawed timber	20–30	8–10	4
21	Poles and piling	15	6–8	1–2
	Sawed timber	15	5–6	1–2
22	Poles and piling	20	5–10	3
23	do	20	10–12	2
24	Land piling	20	14	2
	Marine piling	30	15	1
25	Piling	30–35	8–15	2
	Sawed timber	25–30	6	2
	Conduit	15–20	2	1
26	Piling	20–25	8–12	2
	Sawed timber	20–25	5–10	2
	Cross arms	10–15	5–6	1½–2

[1] Steam pressures are usually applied gradually and the maximum is reached in from 1 to 2 hours. The periods given are for the time of steaming after the maximum steam pressure has been obtained.

Table 3 shows a wide divergence in practice in the steam pressures, steaming time, and vacuum periods used in different treating plants. This is due partly to differences in the size and character of the wood steamed, but probably in greater degree to lack of sufficient knowledge as to the exact steaming conditions required for the best results. The steaming and vacuum should be sufficient to make the wood take treatment acceptably but it should not be severe enough to cause marked loss in strength or damage to the wood. The steaming-and-vacuum period can often be appreciably shortened through the proper control of the subsequent treating conditions (p. 60). From the standpoint of moisture removal practically all that the steaming period accomplishes is the storage of heat in the wood. Subsequently, when the steaming is discontinued, pressure released and a vacuum applied, the stored heat evaporates some of the moisture in the green timber. Experiments show that the moisture content of the wood usually increases to some extent during the steaming period because of condensation. The amount of water absorbed from the steam by the charge of timber will depend to a large extent on the initial moisture content of the wood. Since there is a limit to the amount of heat that can be stored in the wood there is also a limit to the amount of water that can be evaporated by the subsequent vacuum. The average amount of water removed by the steaming-and-vacuum process from green southern pine poles and piling is usually not over 5 to 6 pounds per cubic foot. This would reduce the original average moisture content by between 15 and 20 percent. Practically all this water comes from the sapwood.

With green timber containing exposed heartwood much less water is removed from the heartwood than from the sapwood by the steaming process because the heartwood has a much lower original moisture content and is also very resistant to moisture movement.

Seasoned or partially seasoned wood often shows an increase in moisture after the steaming-and-vacuum treatment is completed (*11*).

Undue attention is sometimes given to the amount of water left in the wood after the timber has been treated. The best criterion is how well the wood is impregnated as indicated by the absorption, uniformity, and depth of penetration and not how much water has been removed by the steaming-and-vacuum treatment. The free water found in the wood after treatment is not evidence of insufficient steaming, since experiments show that except on the surface, even the most effective steam treatment rarely if ever brings the moisture content close to the fiber-saturation point. Moreover, free water remaining in the wood after treatment has no harmful influence on the ultimate checking or durability. The objection that creosoting wood containing free water will prevent subsequent seasoning is not valid because the moisture on the inside of the timber will eventually reach an equilibrium with the surrounding conditions whether the wood is treated or not.

The practice of keeping the steam coils heated during the vacuum period does not aid appreciably in reducing the moisture content of the wood because heat does not circulate freely in a vacuum. While some radiated heat may reach the portion of timbers facing the hot metal surface, most of the timbers in such a charge will be heated very little by radiation.

Most of the water removed by the vacuum is taken out during the early part of the vacuum period when the wood is hottest and evaporation is most rapid. Experiments on green, round southern yellow pine indicate that when a vacuum period of 5 to 6 hours is employed, from 50 to 60 percent of the total water removed is taken out during the first hour of the vacuum period, from 70 to 80 percent in the first 2 hours, from 82 to 88 percent in 3 hours, and from 90 to 95 percent in 4 hours. From the standpoint of moisture removal there seems to be little need to continue the vacuum much longer than 2 hours.

Experiments show that alternate steaming-and-vacuum treatments are considerably more effective in reducing the moisture content of wood than is a continuous steaming and final vacuum period of the same total duration (*17*). In such treatments, however, the steaming periods must be long enough to allow a reasonable time to heat the wood and this will depend upon the size of the timber and the steam temperature.

RATE OF TEMPERATURE CHANGE DURING STEAMING

A knowledge of the rate of temperature change that occurs when wood is heated is necessary if an intelligent selection of steam temperatures and steaming periods is to be made. Otherwise there is no means of evaluating the effect of different steam temperatures or steaming periods on the temperature of the wood at some interior point of timbers of different dimensions. Formulas based on experimental data have been developed at the Forest Products Laboratory that give the relation of the variables affecting temperature changes within the woods tested and make it possible to compute the approximate temperatures to be expected in such material under any given steaming conditions. Methods of conducting the experiments, formulas employed, and data obtained in the laboratory studies of temperature changes in wood are discussed in publications on this subject (*9*, *23*, *25*, *35*, *36*).

TEMPERATURE CHANGES IN GREEN, ROUND, SOUTHERN YELLOW PINE TIMBERS

Figures 9 to 14, inclusive, show the temperatures to be expected at different distances from the circumference after different steaming periods employed for green, round, southern yellow pine timbers when heated with steam at 260° F. and starting with wood at a temperature of 60°. Wood temperatures obtained under other steaming conditions can be found as explained on page 39. The figures show temperatures for intervals of 2, 2½, 3, 3½, and 4 inches from the surface and at the center. These distances should be satisfactory for all practical purposes, even for large sizes of timber, since it is the heat in the outer part of the timber that is most important in evaporating moisture and in assisting penetration. The temperature at the center is important when it is desired to sterilize the entire timber.

Experiments on wood containing different amounts of moisture indicate that the rate of heating is about the same at any moisture content above the fiber-saturation point. For this reason data on temperature changes in green material will apply when the moisture content is about 25 percent or higher.

All curves and computations in this publication showing the time required to obtain a given temperature at some particular point in

the timber are based on the assumption that the full steam temperature is maintained during the heating period. When the temperature is gradually raised and the heating period is measured from the time that the maximum is reached, the wood temperature will naturally be somewhat higher than the computations show. The effect

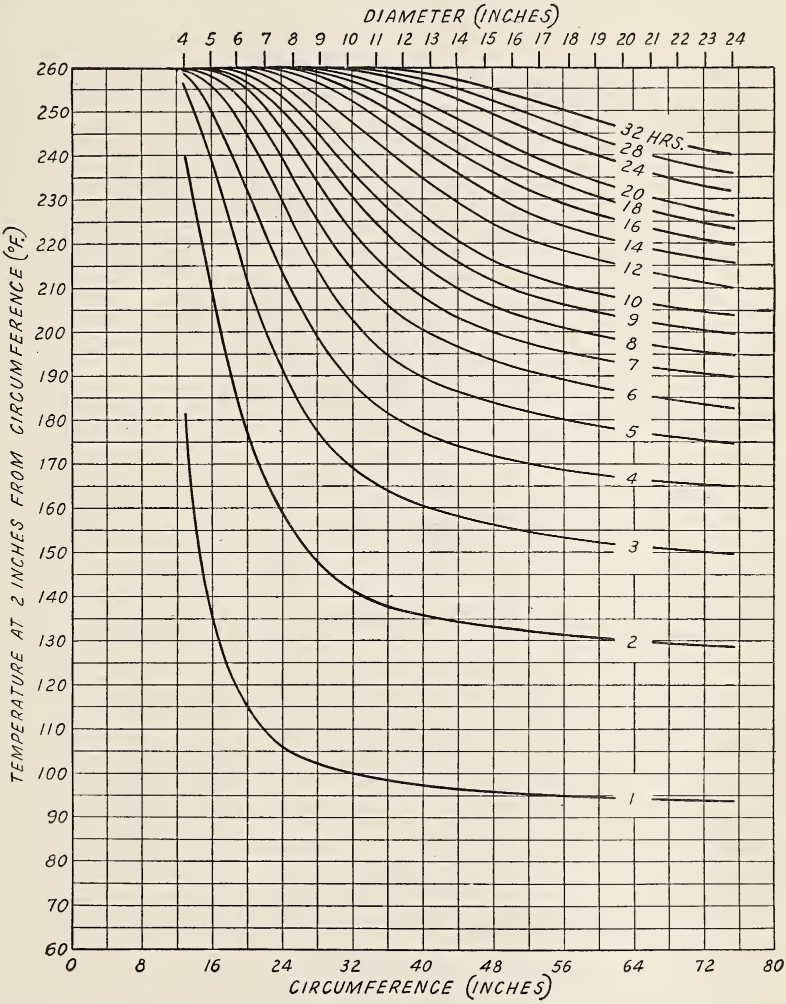

FIGURE 9.—Temperatures at 2 inches from the circumference in round, green, southern pine timbers of different dimensions. (Steam temperature 260° F.; initial wood temperature 60°.)

of this additional heating will depend upon the size of the timbers, steam temperature, time required to reach the maximum temperature, and how the temperature is stepped up during the period it is approaching the maximum. As a rough calculation, if it is desired to take into account the effect of the initial heating period while the steam temperature is being raised, it may be assumed that the heating accomplished is equivalent to that obtained with the maximum

steam temperature applied for one-half the time required to reach the full steam pressure. To illustrate, if 1 hour were taken to reach the maximum temperature and the steaming period is maintained for 8 hours in addition, the total steaming period may be estimated as roughly equivalent to 8½ hours steaming at the maximum tem-

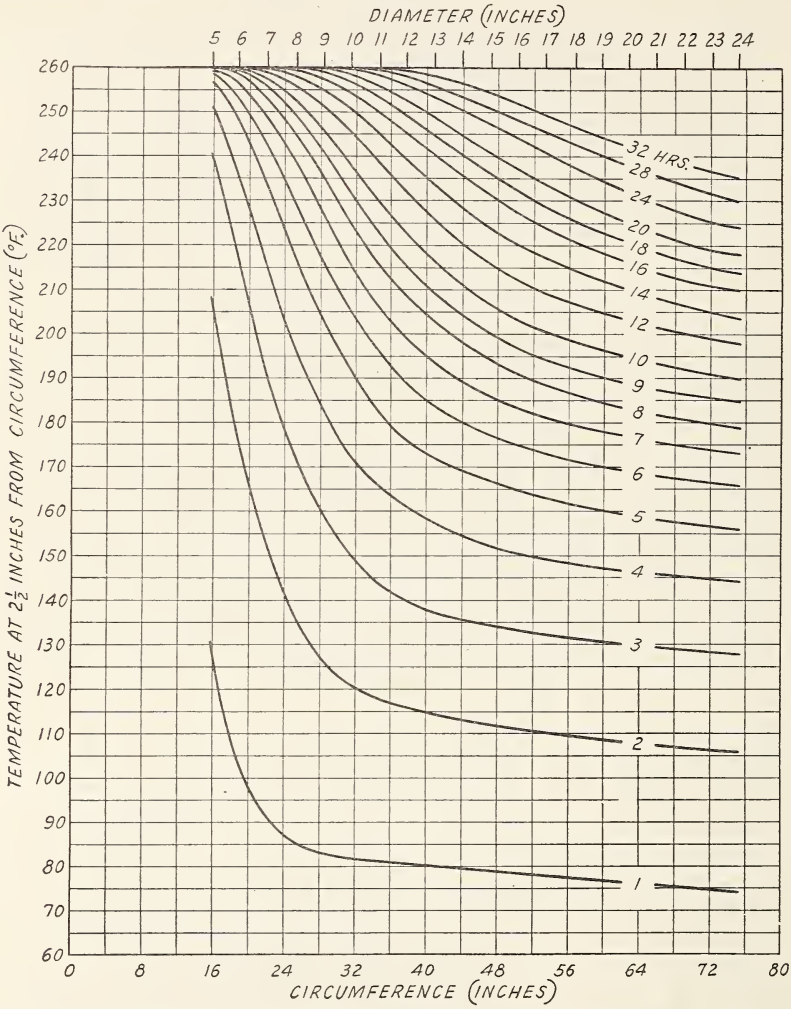

FIGURE 10.—Temperatures at 2½ inches from the circumference in round, green, southern pine timbers of different dimensions. (Steam temperature 260° F.; initial wood temperature 60°.)

perature. The approximate temperature obtained in the timber would then be determined, by means of the proper figure, for the particular point under consideration based on a steaming period of 8½ hours.

The temperatures in the wood are plotted against circumference in inches and the corresponding diameters are shown at the top in inch intervals. Temperature-time curves are given for heating periods of 1-hour intervals up to 10 hours, for 2-hour intervals between 10 and

20 hours, and for 4-hour intervals between 20 and 32 hours. In figure 14, which shows the temperatures at the center, the curves are also given for 8-hour intervals between 32 and 80 hours. The longer time intervals are used when the rate of heating becomes very slow.

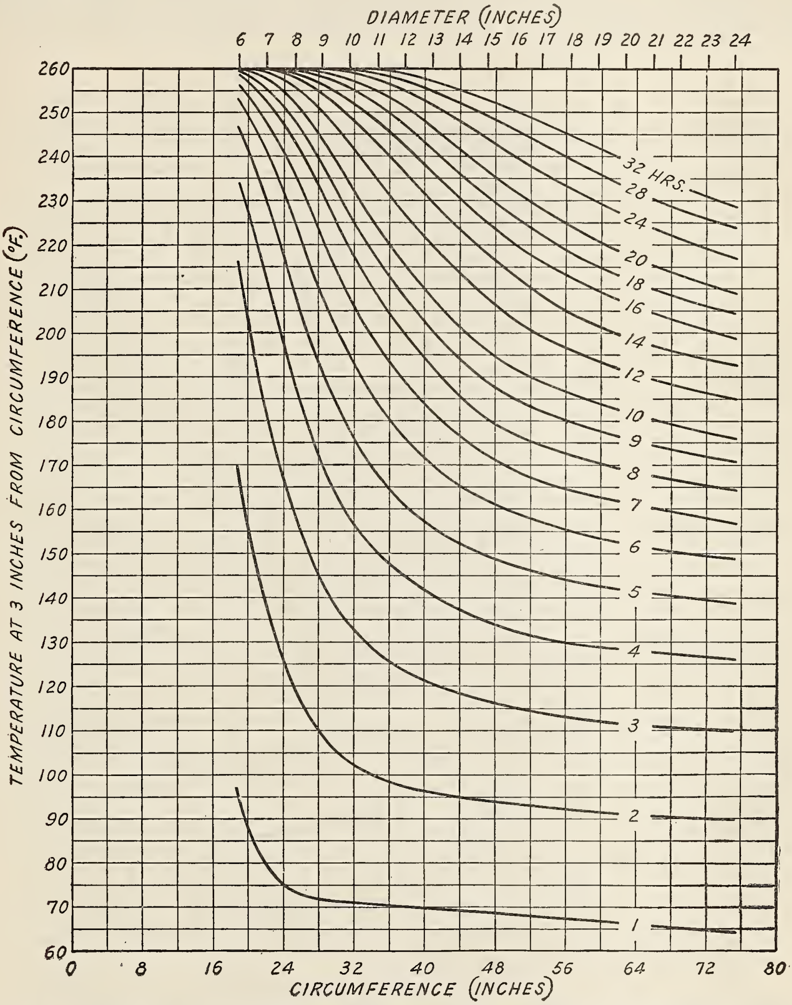

FIGURE 11.—Temperatures at 3 inches from the circumference in round, green, southern pine timbers of different dimensions. (Steam temperature 260° F.; initial wood temperature 60°.)

These intervals are sufficiently close so that it is convenient to interpolate for intermediate values.

The influence of the size of the timber on the time required to obtain a particular temperature is evident from an examination of these curves. To illustrate, figure 14 indicates that the center of a timber 6 inches in diameter reaches a temperature of 235° F. in 4 hours when steamed at 260°, whereas the center of a 12-inch timber reaches only 97° in the same time. Similarly, figure 9 shows that a point 2 inches from the circumference of a 6-inch diameter timber

reaches a temperature of 219° in 3 hours while it requires a steaming period of about 8 hours to reach the same temperature at the same distance from the circumference in a timber 12 inches in diameter. The influence of the diameter on the rate of heating is also strikingly apparent from an examination of figure 14, which shows the rate of temperature change at the center of timbers of different diameter.

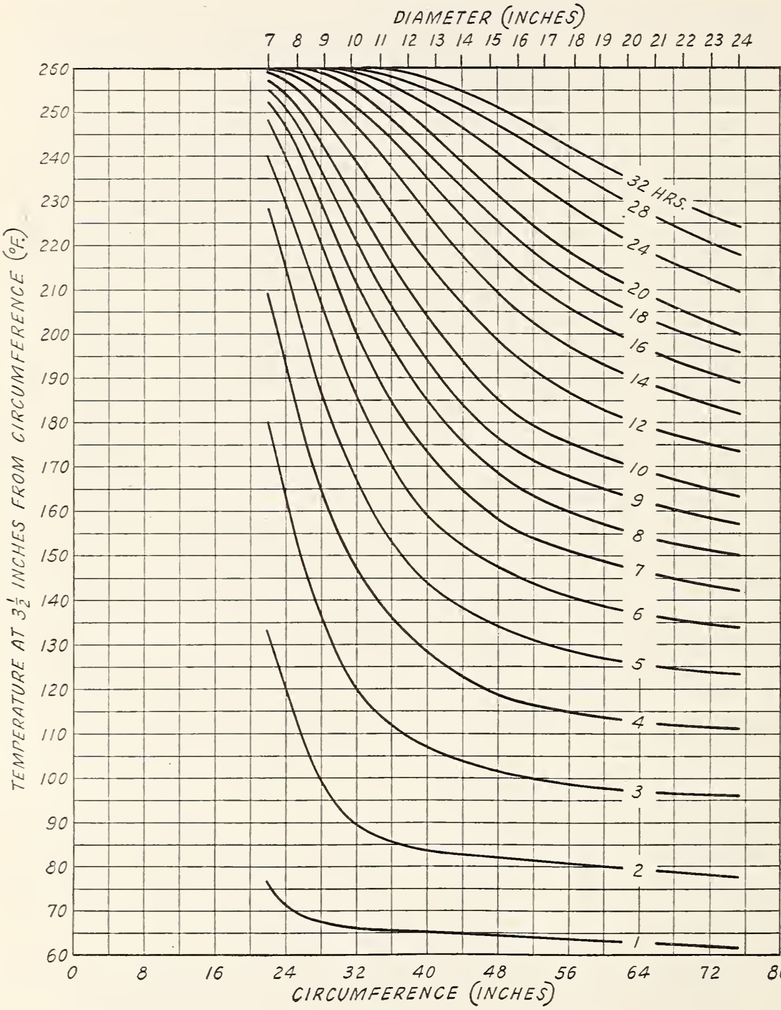

FIGURE 12.—Temperatures at 3½ inches from the circumference in round, green, southern pine timbers of different dimensions. (Steam temperature 260° F.; initial wood temperature 60°.)

Investigations made to determine the temperature conditions that will kill wood-destroying fungi indicate that about 150° F. should be maintained for at least 30 minutes and possibly longer (*8*). Higher temperatures will require less time but sufficient experimental work has not been done to establish the time-temperature relations required to sterilize wood. The curves in figure 14 will be of assistance in estimating the time required to sterilize at the center round timbers

of different diameters. These curves show that some of the large sizes of timber, such as might be used for piling, cannot be heated at the center to 150°, or over without excessively long steaming periods or high steam temperatures that might seriously injure the wood. A 20-inch diameter timber, for illustration, would require about 19

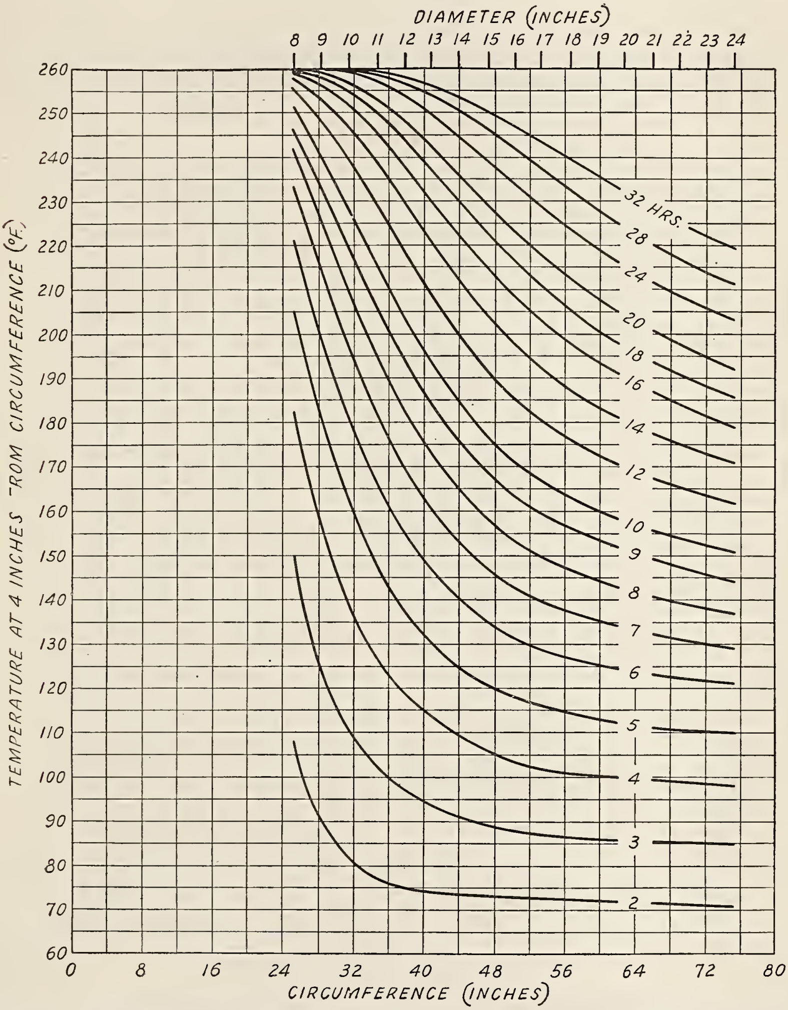

FIGURE 13.—Temperatures at 4 inches from the circumference in round, green, southern pine timbers of different dimensions. (Steam temperature 260° F.; initial wood temperature 60°.)

hours steaming at 260° for its center to reach 150°. The portions of a timber that are penetrated by preservative will, of course, be sterilized by the preservative, regardless of the temperature conditions obtained.

Figure 15 shows the temperatures for 12-inch and 24-inch diameter, round, green timbers at different distances from the circumference for certain definite steaming periods. For example, for a 12-inch diameter

timber steamed 6 hours the third curve from the bottom in the group of curves on the left shows that the temperature would be about 137° F. at the center; 154°, 2 inches from the center; and about 202°, 4 inches from the center. Curves similar to those can be plotted for other timbers from the data given in figures 9 to 14, inclusive.

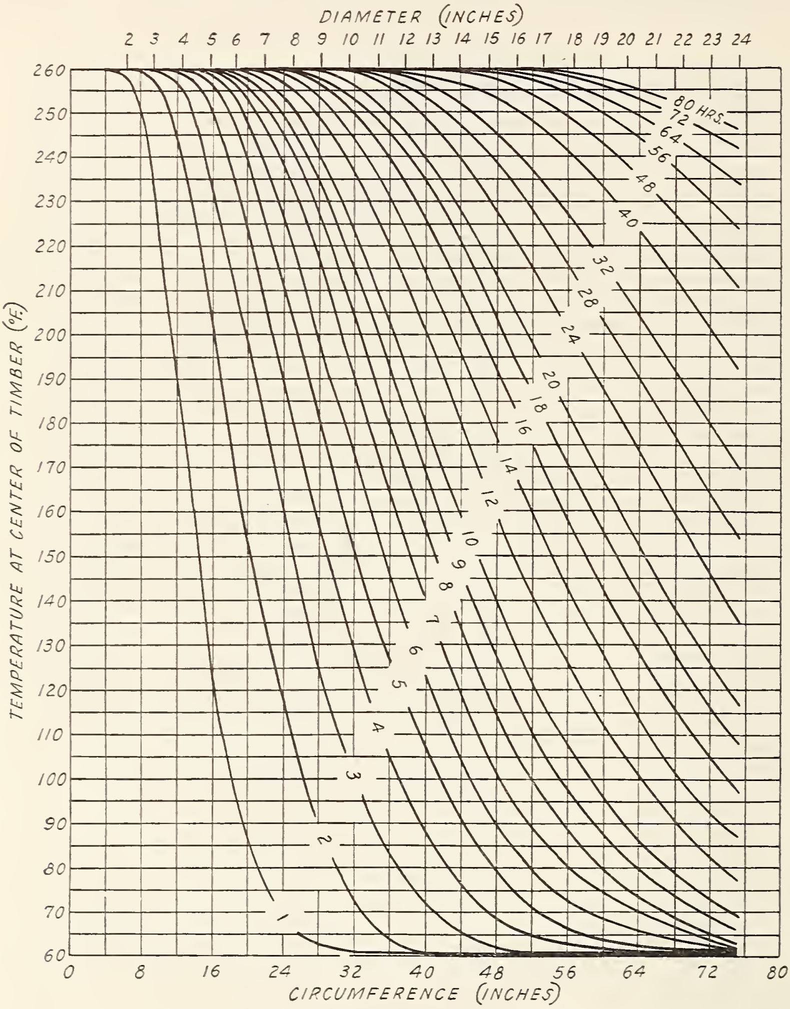

FIGURE 14.—Temperatures at the center of round, green, southern pine timbers of different dimensions. (Steam temperature 260° F.; initial wood temperature 60°.)

If the wood is covered with ice or has water frozen in it a somewhat longer heating period will be required to melt the ice and heat the wood than that shown in the figures. Where there is an ample supply of steam, however, it is probable that most timbers, either round or sawed, would not require more than 20 to 30 minutes additional steaming on this account.

INFLUENCE OF DIFFERENT INITIAL WOOD TEMPERATURES OR DIFFERENT HEATING-MEDIUM TEMPERATURES ON THE TEMPERATURES OBTAINED IN WOOD

Computations of the temperature obtained at various distances from the surface of a timber depend on the diffusivity of the wood for any particular conditions, the shape and dimensions of the timber, the position of the point within the timber for which the temperature is computed, the heating period, the initial temperature of the wood, and the temperature of the heating medium. Original computations of the temperatures obtained at various distances from the surface at any assumed initial wood and heating temperature are very time-

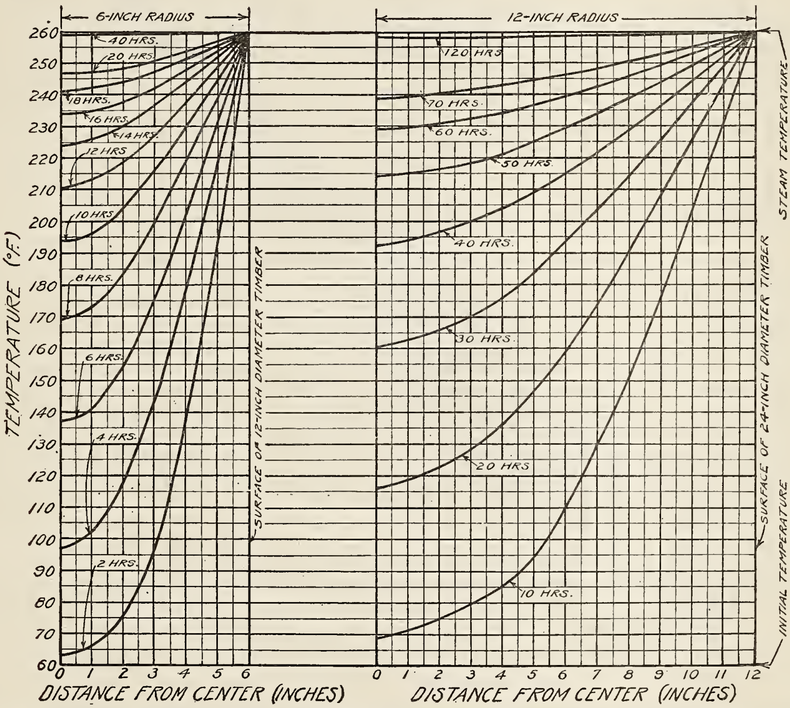

FIGURE 15.—Temperature variations at different distances from the surface in 12- and 24-inch diameter, round, green southern pine timbers when steamed at 260° F.; initial wood temperature 60°.

consuming because of the type of equations involved and the large number of computations required for each different size of timber. After such computations have been made, however, a simple proportional relation (p. 114), which exists between temperatures obtained under different conditions, makes it possible to use the computed data when either the initial wood temperature, the temperature of the heating medium, or both are different from those used in making the original computations.

The same results can be accomplished and arithmetical computations avoided by the use of figure 16 which can be used in conjunction with computed temperature data, either for finding the temperature to be expected at a given point within a timber when heated under various initial wood and heating-medium temperatures or for finding the time required to reach a given temperature at some point in the

timber for any initial wood or heating-medium temperature. Since all temperature computations given in the figures showing temperatures in round and sawed timbers are based on an assumed initial wood temperature of 60° F. and a heating-medium temperature of 260°, the bottom scale on figure 16 covers a range of 60° to 260°.

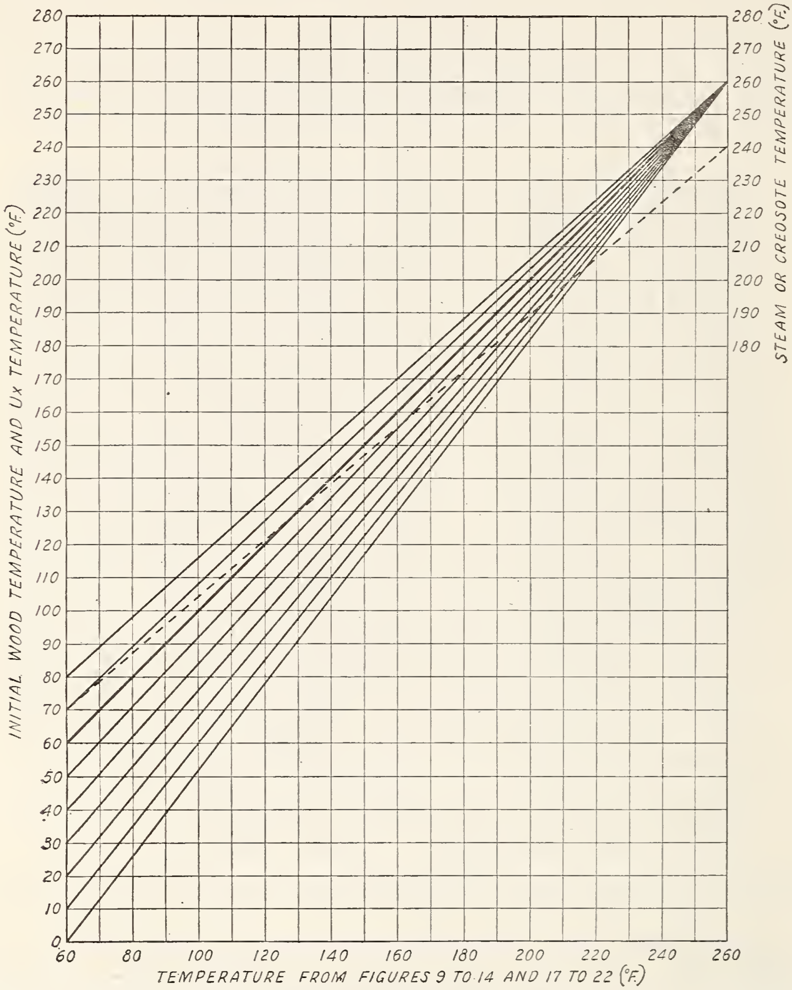

FIGURE 16.—Influence of different initial wood temperatures or different heating-medium temperatures on temperatures obtained in wood.

By placing a straightedge on the point for the initial wood temperature, left-hand scale, and on the point for the heating-medium temperature, right-hand scale, as illustrated by the dotted line, the chart may be used for any heating-medium temperature. The full lines show the position of the straightedge in finding the corresponding temperatures in the timber, for various initial wood temperatures and a heating-medium temperature of 260°.

EXAMPLES OF THE USE OF FIGURE 16

A temperature of 176° F. is shown by figure 11 for a steaming period of 6 hours at a distance of 3 inches from the surface of a 12-inch diameter timber when the initial wood temperature is 60°. What is the temperature at a distance of 3 inches from the surface of this timber when the wood temperature at the start is 30°?

Starting with a temperature of 176° F. on the horizontal scale at the bottom of figure 16, follow vertically to the intersection with the line connecting 30° on the left with 260° on the right. The reading on the vertical scale at the left for this intersection point is 163°, which is the desired temperature.

The steam temperature is 240° F. and the initial temperature of the wood is 70°. What is the temperature after 6 hours steaming at a point 3 inches from the surface of a timber 12 inches in diameter?

Place a straightedge on figure 16 so that it crosses the left vertical scale at 70° F., which is the initial temperature of the wood, and crosses the right vertical scale at 240°, which is the steam temperature. (This procedure is indicated in figure 16 for this example by the dotted line.) After 6 hours steaming at 260° figure 11 shows that the temperature 3 inches from the surface is 176°. Starting on the horizontal scale at the bottom of figure 16 with a temperature of 176°, follow vertically to the intersection with the straight edge (dotted line). The reading on the left vertical scale corresponding with the intersection point is 169°, which is the desired temperature.

The initial wood temperature is 45° F. and the steam temperature is 274° (about 30 pounds steam pressure). How long must a 10-inch diameter timber be steamed to reach a temperature of 200° at the center?

Place a straightedge on figure 16 so that it crosses the left vertical scale at 45° F., which is the wood temperature, and crosses the right vertical scale at 274°, which is the steam temperature. At the desired temperature of 200° on the left vertical scale move horizontally to the right until the point of intersection with the straightedge connecting the wood and steam temperatures is reached. Directly below this intersection point the bottom scale reads about 195°. From figure 14 it is found that with the steam at 260° and the initial wood temperature 60° a temperature of 195° is reached at the center of the timber in about 7 hours. It would therefore require about 7 hours to reach a temperature of 200° with the steam temperature 274° and the wood temperature 45°. In a similar manner it is found that with the same initial wood temperature about 7½ hours are required to heat the center to 200° when the steam temperature is 260° instead of 274°.

In general, increasing the steaming period about one-half to 2 hours, depending on the size, would probably be sufficient to compensate for the slower rate of heating seasoned wood in comparison with green material steamed under the same conditions.

Long poles or piling are often much smaller in diameter at the top than at the butt. For this reason the wood of the top will be heated to a higher temperature than the butt during the steaming period. This should be considered in selecting a steaming period to avoid conditions that may subject the top portion to temperatures that will unnecessarily impair the strength properties.

STEAM PRESSURE AND STEAMING PERIOD

The question as to what steam pressure should be used or how long a given kind of material should be steamed cannot be answered definitely until more is known regarding the effect of steaming on the wood properties and what conditions are the most satisfactory for treatment. Since the surface of the timber is exposed to the maximum temperature conditions during the entire steaming period, the use of too high temperatures may seriously injure the outer portion of the timber.

Temperatures ordinarily used in steaming wood are, of course, much lower than those that burn or char wood but steaming tem-

peratures are sufficiently high that unless care is exercised they may seriously injure the wood. It requires a long time at low steam temperatures to heat the wood sufficiently for treating purposes, and would generally not be practical on this account. The common practice of steaming at 20 pounds gage pressure (approximately 260° F.) may be considered satisfactory until further experiments show otherwise. The use of more severe steaming conditions, such as 30 pounds gage pressure (about 274°) or over does not appear to be justified.

Although there is a definite steam temperature for each steam pressure, nevertheless a thermometer as well as a pressure gage should be used in determining the temperature of the steam within the treating cylinder, because pockets of air are frequently left in the cylinder after the steam is admitted. Where air pockets exist the required pressures may be indicated on the gage when the steam temperature is actually lower than that which should be obtained for the specified pressure. The use of both a thermometer and pressure gage will also serve as a check in case one instrument is in error.

Long steaming periods are unnecessary to obtain the required heating of the wood. Likewise, long vacuum periods are not desirable as the effectiveness of the vacuum is greatly reduced as soon as the temperature of the wood surface is lowered below the boiling point corresponding to the vacuum. The wood merely cools further when the vacuum is continued beyond this point while the evaporation of mositure becomes very slow.

The temperature-time relation given by the curves for both round and sawed timbers shows that after a certain period the temperature changes at an increasingly slower rate and a very long time may be required to gain a few degrees increase in temperature at some interior point.

Although the temperature data do not indicate how many hours steaming are required for the best results, they form a basis for working out such decisions. As an illustration, the operator may begin on the assumption that it is desirable to steam until a temperature of 220° F. is reached at a distance of 2 inches from the circumference. Carefully observing the results obtained will soon show whether the assumption is correct or whether a higher or lower temperature would be more desirable for this point. In this connection, it should be noted that the penetrations and absorptions obtained will depend upon the subsequent treating conditions (p. 60) as well as upon the steaming conditions.

TEMPERATURE CHANGES IN STEAMED, SAWED, SOUTHERN YELLOW PINE

Figures 17 to 21 inclusive show the temperatures to be expected at different distances from the surface along the shorter axis when steaming periods of various lengths are used for sawed, green, southern pine timbers of different sizes and when heating with steam at 260° F. and starting with wood at a temperature of 60°. The shorter axis is considered because temperature changes take place most slowly along the plane of this axis. The figures show time-temperature curves for green timbers 3, 4, 6, 8, 10, and 12 inches thick and ranging in width from the square dimensions to 16 inches. The wood temperatures in figures 17 to 21 are given for each inch from the sur-

face to a depth of 4 inches except for timbers 3 and 6 inches thick for which the temperatures are shown for each 1½ inches from the surface. The data are for heating periods of 1-hour intervals except where the temperature changes are very slow, in which case they are given for each 2-hour period. Temperature readings for intermediate periods can be found by interpolating. Figure 22 shows the temperatures at the center of representative sizes of sawed, green, timbers after various periods of heating.

Figure 16 or formulas (p. 114) can be used for finding the temperature conditions within the sawed timber when the initial wood and

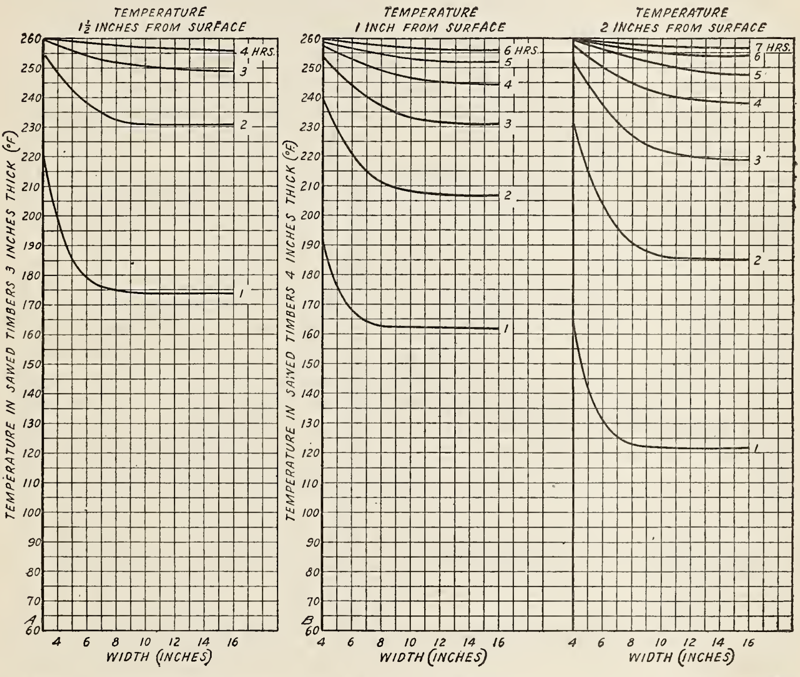

FIGURE 17.—Temperatures in sawed, green, southern pine timbers (*A*) 3 and (*B*) 4 inches in thickness and of various widths. (Steam temperature 260° F.; initial wood temperature 60°.)

steam temperatures are different from 60° and 260° F. in the same manner as described for round timbers.

EXAMPLES OF THE USE OF FIGURE 16 WITH SAWED TIMBER

The initial wood temperature is 50° F., steam temperature 240° (about 10 pounds gage pressure), steaming period 5 hours, and the cross-sectional dimension of timber is 8 by 12 inches. What temperature is to be expected at a point 2 inches from the surface?

From figure 19 the temperature 2 inches from the surface is found to be about 185° F. Place a straightedge on figure 16 so that it connects the point representing the wood temperature of 50° on the left vertical scale with the steam temperature of 240° on the right vertical scale. Starting on the horizontal scale at the bottom of figure 16 with the temperature of 185° which was obtained from figure 19, follow vertically to the intersection with the straightedge. The reading on the left vertical scale corresponding with the intersection point is 169°, which is the desired temperature.

The initial wood temperature of an 8 by 12 inch timber is 50° F. How long a steaming period is required to reach a temperature of 180° at 2 inches from the surface when the wood is steamed at 240°?

On the left vertical scale of figure 16 connect the wood temperature of 50° F. by means of a ruler or straightedge with the steam temperature, 240° on the

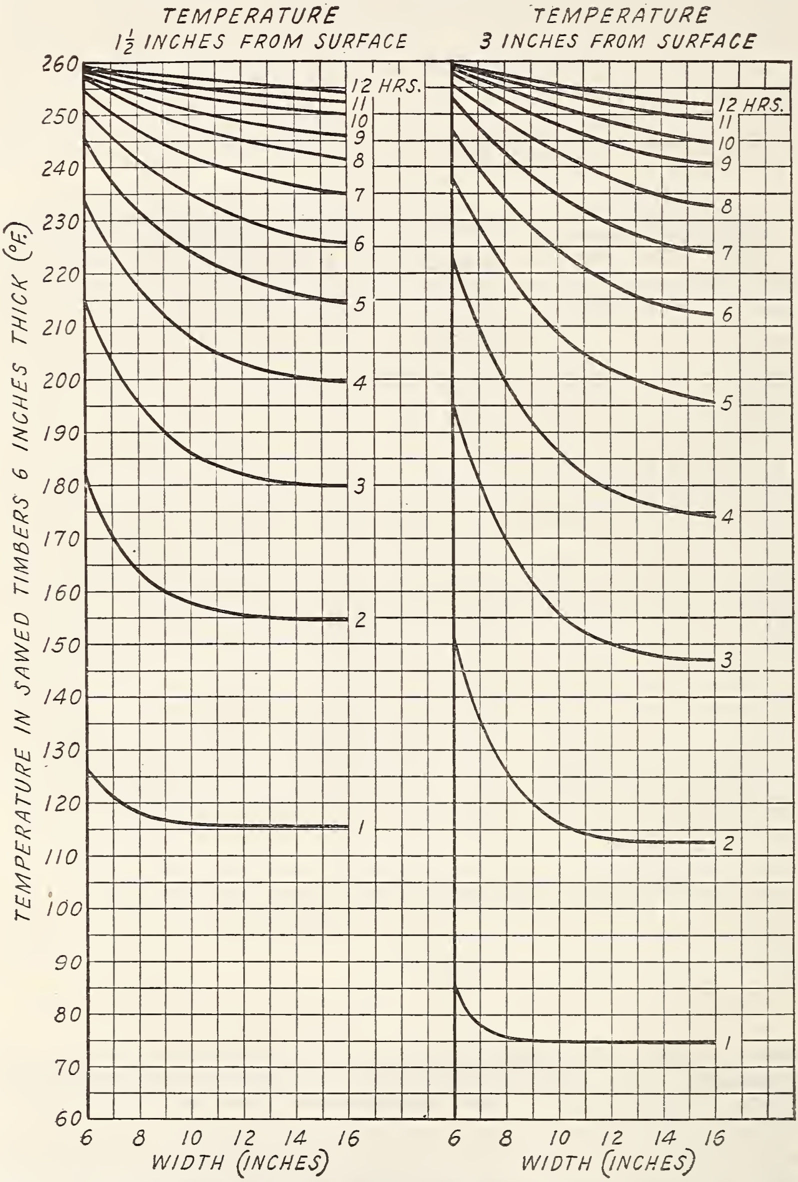

FIGURE 18.—Temperatures in sawed, green, southern pine timbers 6 inches in thickness and of various widths. (Steam temperature 260° F.; initial wood temperature 60°.)

right vertical scale. Starting at the left vertical scale with the desired temperature of 180°, follow horizontally to the intersection with the straightedge. Directly below this intersection, on the horizontal scale at the bottom, the temperature reads about 197°. From figure 19 it is found that a temperature of 197° at 2

inches from the surface is obtained after steaming slightly less than 6 hours. It would therefore require approximately 6 hours steaming at 240° to obtain a temperature of 180° at a point 2 inches from the surface of an 8 by 12 inch timber.

Steaming experiments on sawed, air-seasoned, southern yellow pine specimens which had cross-sectional dimensions ranging from about 3 by 3 inches to 6 by 6 inches showed that the temperature changes were somewhat slower than in the green material. The

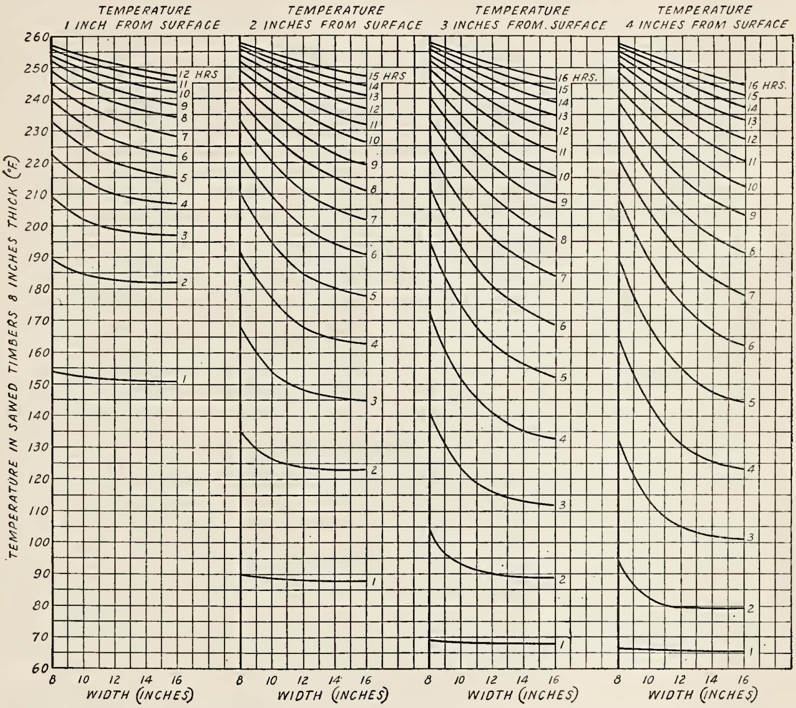

FIGURE 19.—Temperatures in sawed, green, southern pine timbers 8 inches in thickness and of various widths. (Steam temperature 260° F.; initial wood temperature 60°.)

average moisture content of the individual air-seasoned specimens varied from about 14 to 16 percent.

EFFECT OF STEAMING ON STRENGTH AND PHYSICAL CONDITION OF THE WOOD

Steaming at extreme temperatures or for long periods materially reduces the strength of the wood (*6*, *7*). The effect of steaming on the strength of wood is influenced by so many variables that no way has yet been found to apply any definite rule as to how much loss in strength may be expected in timbers of different size, shape, or character for any given set of steaming conditions. In using the steaming process the aim should always be to employ steam temperatures and steaming periods that are as mild as consistent with good absorption and penetration. Some other woods seem more adversely affected than southern yellow pine, but in present practice steaming is not used much with other species.

The effect of steaming on the strength of the wood may not be evident to the eye and there may be considerable loss in strength in timbers that look to be entirely unaffected. Both the visible and the invisible damage should be avoided as far as possible.

From the standpoint of checking and collapse the sapwood of most species is less liable to be damaged by steaming than the heartwood. For this reason round timbers, such as poles and piling, particularly those that are largely sapwood, are able to withstand steaming treat-

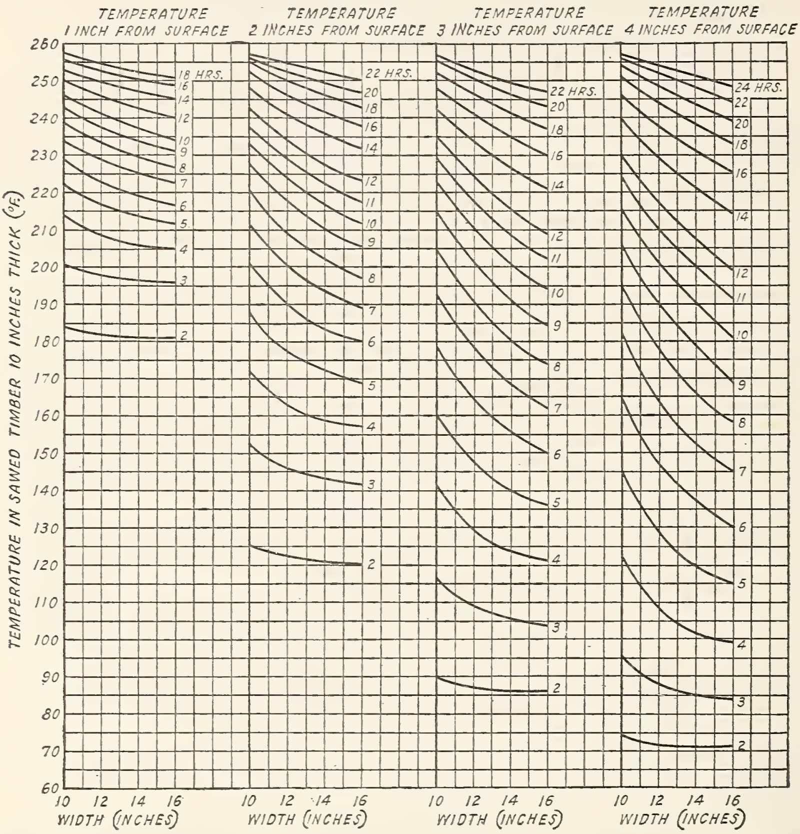

FIGURE 20.—Temperatures in sawed, green, southern pine timbers 10 inches in thickness and of various widths. (Steam temperature 260° F.; initial wood temperature 60°.)

ments that would cause serious checking and collapse in sawed material having exposed heartwood faces. The end surfaces of round timbers, however, may check badly in the heartwood if the steaming conditions are too severe. The same is true of sawed timbers that are largely sapwood but have boxed heartwood. The ends are exposed to more severe conditions than any other part because they are heated in a longitudinal direction as well as from the sides. Heating also takes place most rapidly from the end direction.

In some timbers the growth conditions apparently affect the resistance of the heartwood to checking and collapse. In one instance sawed timbers of rapid-growth wood were found badly end-checked

and collapsed after steaming and treatment in a commercial charge, whereas slower growth material of the same species treated in the same charge was not visibly damaged. It is possible that other characteristics than the rate of growth also had an important bearing on

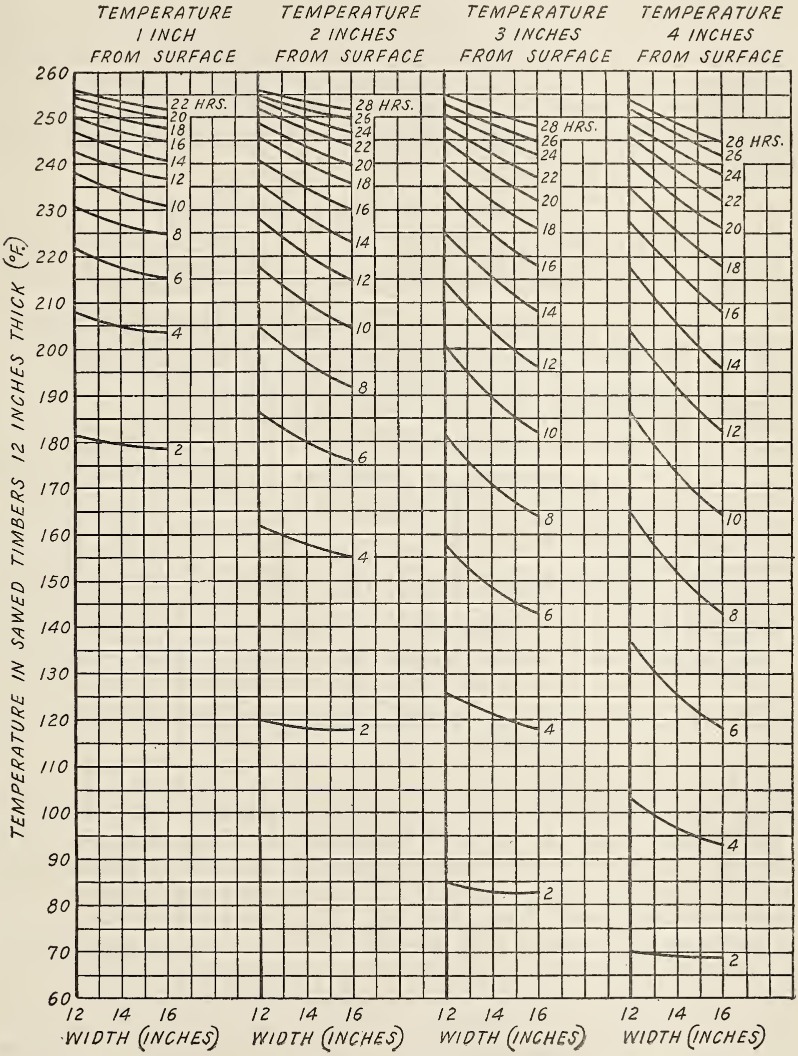

FIGURE 21.—Temperatures in sawed, green, southern pine timbers 12 inches in thickness and of various widths. (Steam temperature 260° F.; initial wood temperature 60°.)

the results observed. Very often wood that has been steamed will appear uninjured if examined immediately after the steaming-and-vacuum treatment, but serious checking and collapse may occur during the subsequent pressure treatment. This indicates that the wood has been at least temporarily weakened by the steam treatment. The remedy is to lower the pressure of the preservative to a point where appreciable checking and collapse are avoided and, if necessary, to

lengthen the pressure period to some extent. Contrary to common belief, reducing the preservative temperature below 200° F. is not necessary. In experiments on several species of conifers it has been found that wood having a high moisture content at the time it is steamed usually shows less tendency to checking and collapse during the preservative treatment than air-seasoned material that has been similarly steamed before treatment. On the other hand, some woods, like the oaks, usually check severely even when the timber is green at the time of steaming. Experiments indicate that steaming may increase checking and shakes, depending on the species and on the steaming conditions employed (*13*).

ADVANTAGES AND DISADVANTAGES OF STEAMING

There is considerable disagreement in the wood-preserving industry as to the merits of steaming. It can be universally agreed that in

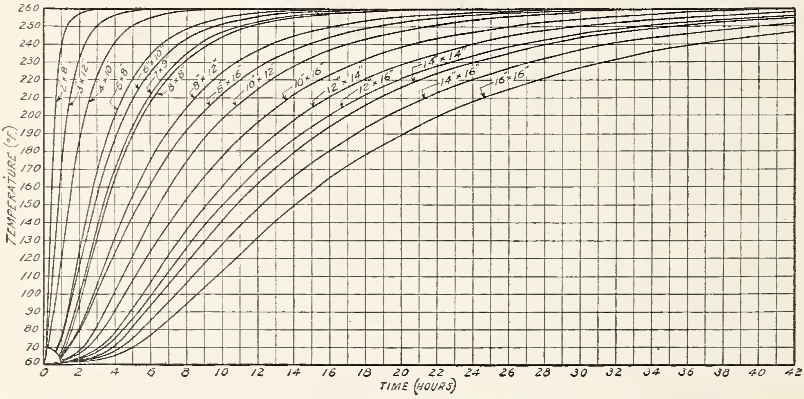

FIGURE 22.—Temperatures at the center of green, sawed, southern pine timbers of different dimensions. (Steam temperature 260° F.; initial wood temperature 60°.)

some species steaming makes good penetrations possible in green timber and that sufficient steaming will insure sterilization of timber in which there may be fungous infection that will not be reached by the preservative. Plant operators opposed to steaming contend that all timber should be air-seasoned before treatment and infected timber should be culled and not treated. As a general rule, both of these recommendations should be followed but they are not always practical. Emergencies often require the treatment of green timber and in some places seasoning conditions are so unfavorable that air seasoning is hazardous and uncertain. Steaming is now used only to a small extent with seasoned timber and is seldom used for species other than southern pine. Seasoned wood can, as a rule, be heated to better advantage by using a sufficiently high preservative temperature.

The steam-and-vacuum treatment may be considered a process that can be employed to advantage under certain limited conditions. It can be very useful and effective when skillfully employed but otherwise may be dangerous to the strength of the wood and very uncertain in its effect.

THE BOULTON PROCESS

The original process for seasoning or conditioning timber by boiling in creosote under vacuum was patented by S. B. Boulton in England in 1879 and in the United States in 1881. This method or some modification of it is now commonly used in conditioning green Douglas fir for treatment and to an increasing extent for certain other species, such as red oak (*19*).

The Boulton process as applied at the present time is essentially as follows: The treating cylinder is filled with hot preservative oil so that all timbers are covered. The oil is then kept heated while a vacuum is applied. The oil serves to keep the wood hot while the vacuum lowers the boiling point of the water in the wood and causes part of it to evaporate. The evaporated moisture and some of the accompanying vapors from the oil pass through a condenser and the rate of accumulation of condensed moisture is a measure of the progress of the conditioning treatment.

In conditioning sawed timbers of Douglas fir by the Boulton process the temperature is customarily maintained at 180° to 200° F. For poles and piling, temperatures of about 200° to 220° are commonly employed. A low vacuum has been commonly used at the start and gradually increased as the moisture evaporation progresses but some plants apply the vacuum as rapidly as possible.

The Boulton process requires time at the start to heat the wood so that water will evaporate from it and the condensate comes off somewhat slowly at first, gradually increasing to a maximum and then gradually decreasing as the heating and vacuum are continued. Increasing the vacuum too rapidly may cause oil to surge over into the vacuum system in plants not specially designed to prevent it. In plants treating Douglas fir the maximum vacuum towards the end of the conditioning period commonly reaches 24 inches of mercury or over. The condensate may be weighed or measured to determine how much water has been removed from the charge. The volatile oils evaporated from the creosote and condensed with the water may be separated from the water and returned to the preservative tank.

Specifications for conditioning Douglas fir by the Boulton process usually require that the heating period be maintained until condensation passing off from the timbers is reduced to approximately one-tenth pound of water per cubic foot of wood per hour. Since the surface area per cubic foot of wood is variable, depending on the dimensions of the material, it is probable that the moisture content in the wood near the surface varies considerably for different classes and forms of timber after conditioning according to this specification. Results obtained will also be influenced by the vacuum and temperature conditions employed. It is difficult to make a specification that will assure uniform results for timbers of different dimensions.

When an empty-cell treatment is specified the cylinder is emptied of preservative after the conditioning period and air at atmospheric pressure or higher is admitted as desired. The preservative treatment is then applied as for air-seasoned material. In treating by the full-cell process the cylinder is filled after the conditioning is completed and pressure is applied at once. Some preservative is ab-

sorbed during the conditioning period, depending on the kind of timber treated, amount of sapwood and heartwood, and other variables.

Although the Boulton process or a modification of it has been employed on the Pacific coast for a long time, it is only within recent years that the process has begun to be used in other parts of the United States for species other than Douglas fir. Unseasoned red oak, which is severely checked by the steam-and-vacuum treatment, has shown but little checking when conditioned by the Boulton method and the results thus far obtained from the treated wood in service appear to be very satisfactory. Green beech and southern yellow pine have also been treated by the Boulton process.

CONDITIONS EMPLOYED FOR THE BOULTON PROCESS

Table 4 gives data on the temperatures and conditioning periods employed in 1930 at various commercial plants using the Boulton process, mostly in the treatment of coast type Douglas fir. Considerable variation in the treating conditions is evident, due in part perhaps to variations in local conditions and timber and in part to the lack of technical data on the details of the process.

TABLE 4.—*Conditions employed at various plants using the Boulton process chiefly for coast type Douglas fir, 1930*

Plant no.	Kind of material conditioned [1]	Boiling under vacuum conditions	
		Boiling	Temperature of preservative during boiling period
		Hours	*°F.*
1	Ties	8 to 12	180 to 200
	Piling	35 to 40	220 to 230
	Partially air-seasoned bridge timbers and lumber	12 to 15	190 to 200
2	Ties	12 to 15	190 to 200
	Poles	35 to 60	190 to 200
	Piling	40 to 60	200 to 220
	Bridge timbers and lumber	12 to 16	190 to 200
3	Piling	38 to 40	200 to 220
	Poles	38 to 40	200 to 240
	Lumber	12	190 to 200
4	Ties	10 to 12	190
	Poles and piling	36 to 48	200 to 210
	Bridge timbers and lumber	21	190
5	Piling	24	180
6	do	35 to 50	190
7	Partially seasoned piling	24	190
	Bridge timbers and lumber	10 to 12	170
8	Partly air-seasoned timbers	15	190
9	Red oak ties, lumber, and bridge timbers	6 to 11	160 to 190
	Beech ties	6 to 12	180
	Southern pine ties and bridge timbers	9 to 13	180

[1] All coast type Douglas fir except as otherwise indicated.

AMOUNT OF MOISTURE REMOVED BY THE BOULTON PROCESS

Table 5 gives the average amount of moisture removed from timber conditioned at some commercial plants using the Boulton process.

TABLE 5.—*Amounts of water collected from green timber of various species conditioned by the Boulton process in commercial treatments*

Species	Charges treated	Kind of material	Average temperature of preservative during conditioning	Average time in hot bath before starting vacuum	Average length of boiling period	Average amount of water collected during boiling period
	Number		°*F.*	*Hours*	*Hours*	*Pounds per cubic foot*
Red oak	11	Ties and bridge timbers	180		24.5	8.7
Beech	7	Switch ties	180		13.5	5.0
Southern pine	7	Ties and timbers	180		11.1	4.6
Douglas fir (coast type).	25	Sawed timbers	180 to 190	4	10.8	1.9
Do	52	Piling	200 to 210	6	43.0	13.4

Table 6 is a summary of data obtained in Boulton treatments on specimens of green southern yellow pine poles. These experiments were made at the Forest Products Laboratory to study the feasibility of using the Boulton process instead of the steaming-and-vacuum method for conditioning green southern yellow pine poles preparatory to treatment (*26*).

TABLE 6.—*Amounts of water collected in Boulton treatment of green southern pine-pole specimens 10 feet long*

Specimens in group (number)	Average diameter of specimens [1]	Temperature of creosote during boiling period [2]	Length of boiling period	Average amount of water collected during boiling period [3]	Specimens in group (number)	Average diameter of specimens [1]	Temperature of creosote during boiling period [2]	Length of boiling period	Average amount of water collected during boiling period [3]
	Inches	°*F.*	*Hours*	*Pounds per cubic foot*		*Inches*	°*F.*	*Hours*	*Pounds per cubic foot*
3	8.2	180	11.0	9.2	3	10.1	210	12.0	9.0
6	9.8	200	10.0	9.3	6	9.8	220	6.6	6.5
6	9.0	200	11.0	9.9	3	10.3	220	11.0	8.3
3	10.8	200	12.0	11.8	6	11.0	220	13.0	13.3
12	11.2	200	13.0	10.5	3	11.3	235	13.0	16.2

[1] Average depth of sapwood about 3.25 inches.
[2] Temperature of preservative maintained constant during entire boiling period except that in some treatments from 15 to 20 minutes were required to reach the desired temperature.
[3] Average initial moisture content of sapwood varied from about 90 to 100 percent.

Sufficient experimental work has not been done to determine definitely whether a preliminary heating period without vacuum has any advantage over the method of applying the vacuum as soon as the oil is admitted to the cylinder. In some early experiments made at the Forest Products Laboratory, in which green Douglas fir timbers of tie size were used, it was found that a larger quantity of water was removed in a given time when the vacuum was applied at the beginning of the heating period than was removed when the wood was first heated 5 hours without vacuum; the total time being the same. These results, however, must be considered as indicative only, since the experiments were not sufficiently extensive to permit definite conclusions.

Although appreciable quantities of water may be removed in the Boulton process, the wood, as in the steaming-and-vacuum process,

may be but partially seasoned and may still have a high average moisture content at the end of the conditioning treatment. Both the heartwood and sapwood of red oak have a very high moisture content when green and in some individual charges treated after conditioning by the Boulton process as much as 9 or 10 pounds of water have been removed per cubic foot of wood. Even then, however, the wood was left very wet. To illustrate, taking the average moisture content of green red oak heartwood as 85 percent (table 1) and the average specific gravity (based on weight when oven-dry and volume when green) as 0.56, the original weight of water is found from figure 7 to be nearly 30 pounds per cubic foot of wood. Assuming 10 pounds of water per cubic foot removed by the Boulton treatment, figure 7 shows that the moisture content of the wood still remains over 56 percent, which is much above the fiber-saturation point. Nevertheless, creosote can be made to penetrate it satisfactorily at this high moisture content.

Green Douglas fir heartwood has an average moisture content of only about 36 percent which, during the Boulton treatment may be reduced appreciably below the fiber-saturation point in the outer inch or so. However, the interior of all but thin material will have little moisture change and the average moisture content may still be considerably above the fiber-saturation point. Using the specific gravity of 0.45 given in table 1 it is found from figure 7 that with 36-percent moisture content the heartwood contains over 10 pounds of water per cubic foot. If the water could be removed as readily and in such large quantities as from red oak or southern pine sapwood, the Douglas fir heartwood could be made very dry by the Boulton process but this is not the case. Experiments made at the Forest Products Laboratory on green Douglas fir heartwood specimens, which were boiled under vacuum at 200° F. for periods of 10 to 20 hours, showed average moisture reductions varying from 8 to 15 percent. The final average moisture content, however, was usually above the fiber-saturation point even in specimens as small as 4 by 4 inches in cross section boiled under vacuum for more than 20 hours. The specimens used in these experiments ranged from about 4 by 4 inches to about 6 by 12 inches in cross section and were from 4 to 7 feet long. Evaporation from the ends was prevented by steel plates with gaskets, which were bolted over the end faces.

Similar experiments were made with green, round, Douglas fir specimens boiled under vacuum for 21 to 23 hours with the preservative held at 190° F. Some of these specimens contained sapwood that averaged from three-fourths to 1¾ inches in thickness for the different pieces. Other specimens were turned in a lathe to remove all the sapwood so that moisture movement through the heartwood was in a radial direction. These various specimens averaged about 10 inches in diameter. The average moisture content of the sapwood before boiling under vacuum was about 100 percent and that of the heartwood about 36 percent. When the boiling period was completed a disk was cut from the mid-section of each specimen and moisture samples were taken of the sapwood alone and of the heartwood at intervals of 1 to 1½ inches from near the surface to the center. The specimens were removed as soon as the boiling period was completed and only very slight absorption of the preservative occurred even in the sapwood. Moisture determinations were made of the

unpenetrated wood only. The final average moisture content of the sapwood varied from about 18 to 42 percent, depending on the original depth. When the average moisture content of the sapwood was brought below the fiber-saturation point the average moisture content of the first inch of heartwood directly under the sapwood was usually 5 to 6 percent higher than that of the sapwood. Otherwise there was very little change in the moisture content of the heartwood covered with sapwood.

With the specimens that were turned in the lathe to remove the sapwood, the average moisture content after the Boulton treatment was about 26 percent for the first 1½ inches from the surface with practically no change beyond that distance.

In these experiments a vacuum of 25 to 26 inches was usually reached within 2 to 3 hours after the preservative was admitted to the cylinder.

There is apparently a high resistance to the movement of moisture in the heartwood of Doulgas fir and it is probable that much of the water removed during the Boulton treatment of this species is from the wood within the first inch or two from the surface. Some plants using the Boulton process for Douglas fir timbers continue the boiling period until the average moisture content within 1 to 1½ inches from the surface has been reduced below the fiber-saturation point. Where the timbers are short and therefore have a considerable amount of end-surface area exposed, more water will be removed than when the timbers are long and moisture movement is largely from the side surfaces. Round Douglas fir piling and poles contain more moisture than sawed material because they have more sapwood and commonly are also kept in the water in log booms until just before treatment. Their average moisture content after treatment is also high. Table 5 shows about 13 pounds of water per cubic foot removed from the round timbers in comparison with about 2 pounds from the sawed material. This difference is to be expected considering the much higher moisture content of the sapwood, higher oil temperatures, longer seasoning periods employed for the piling, and the smaller resistance of the sapwood to moisture movement.

TEMPERATURE CHANGES IN WOOD WHEN BOILED UNDER VACUUM AND WHEN HEATED IN CREOSOTE AT ATMOSPHERIC PRESSURE

Experiments on temperature changes in green, coast-type Douglas fir show that when this wood is either steamed or heated in creosote it heats somewhat faster than does green southern pine for the same heating medium temperatures. Also for the same temperature conditions both Douglas fir and southern pine heat measurably faster when steam is the heating medium than when the wood is heated in creosote.

A study of the rate of temperature change in green Douglas fir heartwood timbers boiled in creosote under vacuum at temperatures of 190° to 210° F. showed that the rate of temperature change was, in general, about the same as when the wood was heated without vacuum until within 5° or 10° of the creosote temperature. For example, with the creosote temperature at 200° and the maximum vacuum about 25 to 26 inches of mercury, the rate of temperature change in these specimens was about the same as without vacuum until a temperature of 190° to 195° was reached. The temperature would then remain fairly constant, so long as the vacuum was not

broken, until the rate of evaporation became sufficiently slow to permit an increase in the wood temperature. In these tests the temperature of the creosote was constant during the boiling period and the maximum vacuum of about 26 inches was reached within an hour.

Experiments on green, round, coast-type Douglas fir specimens boiled under vacuum showed that when the timber contained a considerable amount of sapwood the rate of temperature change was about the same as when the wood was heated at atmospheric pressure, until a temperature about 20° to 25° lower than the creosote temperature was reached. Beyond this limit the rate of temperature change was usually much slower than when the wood was heated at atmospheric pressure because further temperature increase was retarded by the evaporation of moisture. The diameter of these specimens varied from about 9 to 12 inches and the sapwood depth varied from ¾ to 1½ inches. The moisture content of the sapwood averaged about 100 percent for the different specimens and that of the heartwood about 36 percent. In these experiments on round specimens the preservative temperature was kept constant during the boiling period and the maximum vacuum of 25 to 26 inches was usually reached within 2 or 3 hours after the test was started. The total boiling period was from 21 to 23 hours.

In green, round, southern pine timbers boiled under vacuum the effect of vacuum on the rate of temperature change was more pronounced than that noted for round Douglas fir timbers because of the greater depth of sapwood in the pine and consequent higher rate of evaporation. The rate of temperature change in the round pine specimens boiled under vacuum was about the same as when heated without vacuum until the wood reached a temperature about 35° or 40° below the creosote temperature. The wood temperature then changed but little until a considerable amount of water had been removed from the sapwood.

The increase in temperature above the boiling point corresponding to the vacuum conditions used in the Boulton process is largely because of the resistance of the wood to air and moisture movement. In other words, the vacuum within the timber is less than that surrounding it and may decrease rapidly from the surface to the interior. As a matter of fact, pressure measurements in heart-wood timbers have shown that an appreciable pressure can be built up and remain for hours in the interior of the heated wood with a high vacuum surrounding it. As might be expected, the vacuum will affect the rate of temperature change within the timber to a greater extent in wood that has a large proportion of sapwood than it will in wood that is largely heartwood and therefore very resistant to the movement of liquids and vapors. No temperature measurements were made in red oak while boiled under vacuum but the effect of the vacuum on temperature changes would undoubtedly be very pronounced in this species on account of its open porous structure.

In addition to the effect of the resistance of the wood on interior temperatures, a certain increase in wood temperature above the boiling point corresponding to the vacuum is also necessary to overcome the pressure due to the weight of the preservative above the timber. When the wood begins to season below the fiber-saturation point in the surface portion, the resistance to moisture movement increases and a correspondingly higher wood temperature is necessary to overcome

this resistance. As the wood dries below the fiber-saturation point its diffusivity decreases which tends further to retard the rate of temperature rise. If the boiling period is continued a sufficient length of time the temperature throughout the timber will eventually become about the same as that of the heating medium.

The average diffusivity factor of green Douglas fir timbers heated in creosote without vacuum was found to be nearly the same as that of green southern pine when heated in steam. For this reason figures 9 to 15, prepared for round timbers, and figures 17 to 22 for sawed timbers, can be used for finding the rate of temperature change in corresponding sizes of green Douglas fir heated in creosote at atmospheric pressure and also, over a large part of the wood-temperature range, for timbers boiled under vacuum. For such purposes it is merely necessary to determine the proportional wood temperature by means of figure 16 or to substitute the creosote temperature and initial wood temperature in the formula given on page 114.

In timbers of small cross section a considerable proportion of the wood may season below the fiber-saturation point during the boiling period and the rate of heating will be retarded as seasoning progresses. It would therefore give closer results to assume that sawed timbers less than 5 inches thick or round timbers less than 8 inches in diameter, when boiled under vacuum, heat at about the same rate as air-seasoned wood. The rate of temperature change in air-seasoned wood is discussed on page 57.

Since the rate of temperature change in green, sawed Douglas fir heartwood timbers heated in creosote under vacuum is about the same, over the larger part of the temperature range, as when the material is heated without vacuum, the method of estimating the temperature within the wood when heated at atmospheric pressure will apply quite well for sawed timbers boiled under vacuum. In general, the rate of temperature change at any particular point in heartwood timbers boiled under vacuum can be considered to be about the same as when heated without vacuum, until the wood temperature is within 10° to 15° of the creosote temperature.

As in the case when steam is the heating medium (p. 32), temperature computations for wood heated in creosote are based on the assumption that the oil temperature is constant during the heating period.

EXAMPLES OF HOW TO DETERMINE THE APPROXIMATE TEMPERATURE IN GREEN SAWED HEARTWOOD COAST TYPE DOUGLAS FIR TIMBERS BOILED UNDER VACUUM OR HEATED AT ATMOSPHERIC PRESSURE

A 6- by 10-inch timber at an initial temperature of 50° F. is heated in creosote under vacuum at 180°. What is the approximate temperature at the center (3 inches from the surface) after the wood has been heated for 4½ hours?

Figure 18 shows that after 4½ hours heating the computed temperature, based on the initial wood temperature and heating-medium temperature of 60° and 260° F., respectively, is about 197°. Place a straightedge on figure 16 so that it connects the point representing the wood temperature of 50° on the left vertical scale with the creosote temperature of 180° on the right vertical scale and reading across to the left scale from a point directly above 197° on the bottom scale, the temperature desired is found to be about 139°.

What is the time required to reach a temperature 15° F. lower than the creosote temperature for the point named in the preceding example?

The temperature required would then be 180°−15° or 165° F. Place a straightedge on figure 16 connecting the wood temperature of 50° on the left vertical scale with the creosote temperature of 180° on the right vertical scale and

read horizontally from a temperature of 165° on the left vertical scale to the intersection with the straightedge. Directly below this intersection, on the horizontal scale at the bottom, the temperature is found to be about 237°. From figure 18 it is found that a temperature of 237° is obtained at the center of a 6 by 10 inch timber, under the heating conditions used in computing the curves in about 7⅓ hours. This is also the approximate time required to reach a temperature of 165° at the point under consideration when the timber is boiled under vacuum and the initial wood temperature is 50° and the creosote temperature 180°.

Computations of the time required to obtain wood temperatures somewhat higher than 165° F. for the creosote temperature of 180° assumed in the preceding example would not be so reliable for, as previously mentioned, the rate of temperature change in heartwood timbers boiled under vacuum may become slower, after the wood temperature is within 10° to 15° of the creosote temperature, than would be the case if the wood were heated at atmospheric pressure. Computations for heating at atmospheric pressure could, of course, be made for the entire temperature range since no vacuum effect would need to be considered.

The approximate wood temperature in green, round, Douglas fir timbers boiled under vacuum can be computed in the same manner as illustrated for sawed timbers by using figure 16 and the required data from one of figures 9 to 14, inclusive. It must be borne in mind, however, that time-temperature curves for round timbers boiled under vacuum may be expected to diverge, after a period of heating, from curves that would be obtained if the wood were heated without vacuum. Factors affecting the results to a greater or less extent will be diameter of timber, moisture content of sapwood, depth of sapwood, temperature of the preservative, rate of applying vacuum, and maximum vacuum applied. For general conditions, however, it should be sufficiently close to assume that in boiling under vacuum the curve for the rate of temperature change at any particular point in a timber will be about the same as would be obtained if no vacuum were used until a temperature about 25° lower than the preservative temperature is reached. On this basis if the round timbers were boiled at 215° F., the rate of temperature change at a fixed distance from the surface can be assumed to be about the same as if the wood were heated at 215° without vacuum until a temperature of 190° is reached. The temperature would then probably change very slowly or remain fairly constant until seasoning had progressed sufficiently to require a higher temperature for further seasoning.

As in the case of green southern pine timbers it was found in tests at the laboratory that green Douglas fir heats at about the same rate for all moisture-content values above the fiber-saturation point.

EXAMPLES ILLUSTRATING METHOD OF FINDING APPROXIMATE TEMPERATURES IN A GREEN, ROUND, DOUGLAS FIR TIMBER BOILED UNDER VACUUM OR HEATED AT ATMOSPHERIC PRESSURE

A green, round, Douglas fir timber with a circumference of 32 inches has an initial temperature of 70° F. and is heated in cresote under vacuum at 200°. What is the approximate temperature at a distance of 2½ inches from the surface after heating for 6 hours?

From figure 10 the temperature 2½ inches from the surface is found to be about 203° F. after 6 hours of heating. Place a straightedge on figure 16 so that it crosses the left vertical scale at 70°, which is the initial wood temperature, and crosses the right vertical scale at 200°, which is the temperature of the preservative or heating medium; starting on the horizontal scale at the bottom of figure 16 follow vertically from 203° to the intersection with the line connecting 70° on

the left vertical and 200° on the right vertical scale. The temperature (Ux) on the left vertical scale corresponding with this intersection point is about 163° which is the desired temperature.

How long a time is required to reach a temperature of 175° F. at 2½ inches from the surface in a timber 32 inches in circumference with the initial wood temperature 70° and the creosote temperature 200°?

With a straightedge connection 70° F. on the left and 200° on the right vertical scale of figure 16, follow horizontally from 175° on the left scale to the line connecting 70° and 200°, respectively. Directly below the point of intersection the temperature on the bottom scale is found to be about 222°. From figure 10 it is found that about 8 hours are required to obtain this temperature. The time required to obtain a temperature of 222° with the initial wood and heating medium temperatures of 60° and 260°, respectively, is the same as the time required to reach a temperature (U_x) of 175° at the same point in the timber when the respective initial wood and heating medium temperatures are 70° and 200°. The temperatures found from figure 16 can also be determined by means of formulas (p. 114).

Experiments on green southern pine heated in creosote at atmospheric pressure showed that in order to obtain the same wood temperature the heating period should be increased about 20 percent over that required when steam at the same temperature is the heating medium.

Although the rate of temperature change in green Douglas fir and green southern pine is not appreciably affected by changes in moisture content above the fiber-saturation point, experiments show that the diffusivity factor and hence the rate of heating decreases as the wood seasons below the fiber-saturation point.

The curves shown in figures 9 to 14 and 17 to 22 can also be used for finding the approximate time required to heat round or sawed air-seasoned Douglas fir or southern pine timbers in creosote to obtain a given temperature at various distances from the surface. As in the case of green material, figures 9 to 14 are to be used for round timbers and figures 17 to 22 for sawed material. Douglas fir timbers seasoned to an average moisture content of about 12 to 15 percent should have the heating period (in oil with or without vacuum) increased about 15 percent over that indicated by the curves for the particular heating conditions employed. Similarly, southern pine air-seasoned to about the same average moisture content should have the heating period (in oil) increased about 35 percent over that shown by the curves. The proportional wood temperature can be determined for the heating conditions used by means of figure 16 or the formulas given on page 114, as described for green pine and green Douglas fir.

EXAMPLE OF HOW TO DETERMINE THE APPROXIMATE TEMPERATURE IN SEASONED WOOD HEATED IN CREOSOTE AT ATMOSPHERIC PRESSURE

Air-seasoned sawed timbers 10 by 12 inches in cross section are treated under the following conditions: Creosote temperature 190° F., initial wood temperature 70°, and pressure period 7 hours. What is the approximate temperature at a distance of 2 inches from the surface at the end of the pressure period if the wood is Douglas fir? If the wood is southern pine?

Since the heating period for air-seasoned Douglas fir should be increased about 15 percent to obtain a temperature corresponding to that shown by the curves in figures 17 to 22 for the heating conditions employed, this will be equivalent to $\frac{7}{1.15}$ or about 6.1 hours if the rate of heating were the same as indicated by the curves for the timber under consideration. From figure 20 it is found that in 6.1 hours the temperature 2 inches from the surface of a 10 by 12 inch timber is about 192° F. with the initial wood and heating-medium temperatures as assumed in computing the curves, namely, 60° and 260°. In order to find the temperature at this point when the initial wood temperature is 70° and the heating medium

temperature is 190°, place a strightedge on figure 16 so that it connects 70° on the left vertical scale and 190° on the right vertical scale. Follow vertically from a temperature of 192° on the bottom scale to the intersection with the strightedge. Directly across on the left vertical scale the desired temperature is found to be about 149°.

In like manner it would be found that air-seasoned pine timbers of the same dimensions would be heated in 7 hours to a temperature equivalent to that obtained in $\frac{7}{1.35}$ or about 5.2 hours under conditions shown by the curves after adjusting by means of figure 16 for the initial wood temperature and creosote temperature assumed. This would show a temperature of about 142° F. at 2 inches from the surface in seasoned pine timbers or 7° lower than the temperature in seasoned Douglas fir under the same heating conditions.

The temperature changes in seasoned wood heated in oil would be little influenced by vacuum because heat consumption due to moisture evaporation would be slight.

If the timbers had a large amount of sapwood so that the preservative could penetrate a considerable distance from the surface the temperature would, of course, be higher than that shown by the computations since more or less heat would be carried in by the preservative. In the case of heartwood timbers penetration is usually very limited and the heating effect of the creosote that penetrates the timber would not have such an important influence especially when the cross-sectional dimensions are fairly large.

EFFECT OF BOULTON PROCESS ON STRENGTH

One of the principal reasons for using the Boulton process on Douglas fir is to overcome the damaging effects that would result from the high temperatures of the steaming process or from boiling in creosote at high temperatures as was formerly the practice. With the milder heating conditions used in the Boulton process these effects are much less (*34*). In the use of the Boulton process, as in the steaming-and-vacuum method, the preservative temperature and length of the heating period should be restricted as much as practicable consistent with good treatment.

ADVANTAGES AND DISADVANTAGES OF THE BOULTON PROCESS

The chief advantage of the Boulton process in comparison with the steaming-and-vacuum method for preparing timber for treatment lies in the milder temperatures that can be employed, making possible good treatment with minimum effect on the strength and on the physical condition of the wood. This is the determining factor in the choice of a conditioning process for woods that are sensitive to high temperatures.

Other advantages are that the Boulton treatment never increases the moisture content of the wood or of the oil and a greater moisture reduction can be obtained than is possible with the steaming process. Steaming adds moisture to seasoned or partially seasoned wood and it is often necessary to dehydrate the preservative oil at intervals when treating steamed material. With the Boulton process, however, it is possible to reduce the moisture content of green timbers below the fiber-saturation point for the first inch or two from the surface.

The Boulton process is sometimes employed for seasoned or partially seasoned wood but, in general, there is little advantage to be

gained by using it under such conditions when the other treating conditions are properly selected.

The chief disadvantages of the Boulton process are that it is suitable for oils only, it often costs more than air-seasoning, and heats the wood more slowly than steaming or boiling at high temperatures without vacuum.

MECHANICAL PREPARATION

INCISING

During recent years the practice of incising resistant woods prior to treatment has become common. With sawed material incising is done by passing the timbers through a machine equipped with cutting teeth projecting from rollers.[8] As the timber passes through the machine the teeth are pressed into the wood, forming a predetermined pattern of incisions that penetrate to a specified depth, usually one-half, five-eighths, or three-fourths of an inch.

The utility of incising depends on the fact that longitudinal penetration is much greater in most species than either radial or tangential penetration. The incising teeth cut, tear, or break the wood fibers so that some end-grain wood is exposed to the preservative and penetration takes place longitudinally in both directions from each incision. There is also some side penetration but this is usually very slight. In order to get complete penetration of all the wood to the depth of the incisions, the holes must be spaced properly along and across the surface so that the preservative will meet as it spreads from the holes and leave no unpenetrated places. The necessary spacing is worked out empirically. On the other hand, the holes should not be more numerous than necessary so that the strength of the wood will not be greatly impaired.

Incising is least effective in resistant woods that cannot be penetrated well longitudinally. In suitable woods, however, it is an effective means of getting uniform depth of penetration in heartwood.

FRAMING, ADZING, AND BORING

Whenever practicable all framing, adzing, or boring of ties, poles, or structural timbers of any kind should be done before treatment. Cutting into timber after treatment exposes untreated wood that is difficult to protect properly by any surface treatment applied afterwards. The life of the structure may be seriously affected or maintenance costs increased when such cutting is permitted. Preframing at a properly equipped plant has often the additional advantage of costing less than framing on the job. The practice of preframing is growing rapidly in preparing timber for railway structures (*27*, *29*).

Boring and adzing ties before treatment has an important bearing on the effectiveness of treatment. Adzing before treatment avoids the danger of cutting into untreated wood and boring the ties makes it possible to penetrate the wood in the spike holes where decay often starts in ties that have not been bored.

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[8] The incising of ties and timbers was patented in the United States in 1918 by O. P. M. Goss. This patent, no. 1,252,428, was purchased by the Pacific coast wood-preserving companies and was dedicated by them to the free use of the public.

INJECTING PRESERVATIVES

The character and viscosity of the preservative, preservative temperature, vacuum, air pressure, preservative pressure, and length of pressure periods all have a marked effect on treatment and are so closely interwoven that the relative influence of an individual factor is often unrecognized. Their importance is greatest in wood that is resistant to treatment or in mixtures of easily treated and resistant wood.

INFLUENCE OF VISCOSITY AND TEMPERATURE OF PRESERVATIVE

Preservatives differ considerably in the ease with which they can be made to penetrate resistant wood. The principal property involved

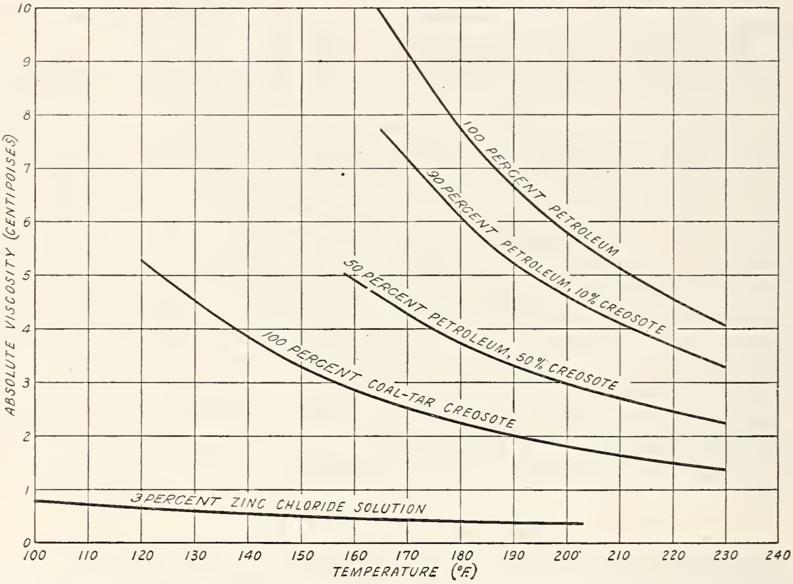

FIGURE 23.—Temperature-viscosity curves for a representative coal-tar creosote, petroleum oil, mixtures o the petroleum oil and creosote, and for a 3-percent zinc chloride solution.

is viscosity (*2, 14, 15, 16, 18*). Other factors, such as surface tension or ability to wet the wood, are probably also of importance but the extent to which their influence is different from that of viscosity has not been established.

The viscosity of a preservative varies with its temperature and the two cannot be discussed independently.

Figure 23 illustrates variations in viscosity of different preservative oils. The figure gives temperature-viscosity curves for a representative coal-tar creosote, a petroleum oil, and mixtures of the creosote and petroleum oil. The petroleum and creosote were those used in making the treatments the data for which are given in table 7. The curve for 3-percent zinc chloride solution has been added for comparison. The marked differences in viscosity between the creosote, the petroleum, and the mixtures, stand out clearly. The low viscosity of the water solution, in comparison with the viscosities of the oils, is also noteworthy. The differences decrease greatly, however, as the temperature increases.

TABLE 7.—*Effect of temperature on absorption and penetration in air-seasoned eastern hemlock ties treated by the full-cell process with creosote and creosote-petroleum mixtures*[1]

Preservative	Gage pressure	Ties in treatment	Average weight per cubic foot before treatment	Preservative temperature	Average net absorption	Average gross absorption	Average side penetration		Absolute viscosity of temperature used in treatment		Average net absorption per square foot of surface		Average gross absorption per square foot of surface	
	Pounds	*Number*	*Pounds*	° *F.*	*Lbs. per cu. ft.*	*Lbs. per cu. ft.*	*Inches*	*Percent*	*Centipoises*	*Percent*	*Pounds*	*Percent*	*Pounds*	*Percent*
Coal-tar creosote	125	25	29.3	140	9.5	9.8	0.26	100	3.80	100	1.31	100	1.35	100
	125	24	29.4	160	10.3	10.7	.32	123	2.81	74	1.41	108	1.46	108
	125	24	30.0	180	12.8	13.3	.39	150	2.22	58	1.75	134	1.82	135
	125	25	28.4	200	15.7	16.2	.43	165	1.80	47	2.14	163	2.21	164
	125	25	29.2	220	16.4	19.0	.48	185	1.50	40	2.25	172	2.60	193
	125	25	28.5	240	16.4	21.7	.49	188	1.22	32	2.22	170	2.93	217
Average			29.1	190	13.5	15.1	.40		2.22		1.85		2.06	
Coal-tar creosote	150	25	30.7	140	8.2	8.6	.26	100	3.80	100	1.12	100	1.17	100
	150	25	29.4	160	12.7	13.5	.40	154	2.81	74	1.75	156	1.86	159
	150	25	30.2	180	14.7	15.9	.42	161	2.22	58	2.01	180	2.17	186
	150	24	29.8	200	16.2	19.2	.52	200	1.80	47	2.24	200	2.65	227
	150	25	30.3	220	18.5	24.5	.65	250	1.50	40	2.55	228	3.37	288
	150	25	30.3	240	18.1	27.6	.72	277	1.22	32	2.49	222	3.81	326
Average			30.1	190	14.7	18.2	.50		2.22		2.03		2.50	
Coal-tar creosote	175	24	29.1	140	12.0	12.9	.35	100	3.80	100	1.64	100	1.76	100
	175	24	28.3	160	16.0	17.3	.44	126	2.81	74	2.18	133	2.35	134
	175	24	29.3	180	15.7	17.0	.53	151	2.22	58	2.26	138	2.45	139
	175	23	29.4	200	17.1	19.4	.57	163	1.80	47	2.43	148	2.76	157
	175	22	29.5	220	21.5	26.1	.71	203	1.50	40	2.93	179	3.57	203
	175	23	30.3	240	21.8	33.6	.81	231	1.22	32	3.13	191	4.82	274
Average			29.3	190	17.4	21.1	.57		2.22		2.43		2.95	
50 percent petroleum oil and 50 percent coal-tar creosote	150	24	32.7	160	10.7	11.2	.30	100	4.90	100	1.65	100	1.71	100
	150	24	32.5	180	11.1	11.5	.35	117	3.80	78	1.68	102	1.74	102
	150	24	32.2	200	13.4	14.0	.44	147	3.05	62	2.00	121	2.09	122
	150	24	34.0	220	11.8	13.0	.47	157	2.40	49	1.82	110	2.06	121
Average			32.9	190	11.8	12.4	.39		3.54		1.79		1.90	
90 percent petroleum oil and 10 percent coal-tar creosote	150	24	30.8	160	10.0	11.2	.24	100	8.30	100	1.35	100	1.50	100
	150	24	31.0	180	9.2	10.6	.33	138	6.05	73	1.26	93	1.37	91
	150	24	31.7	200	10.2	10.9	.37	154	4.60	55	1.52	113	1.64	109
	150	24	31.2	220	11.6	13.9	.45	188	3.62	44	1.66	123	1.98	132
Average			31.2	190	10.3	11.6	.35		5.64		1.45		1.62	

[1] Preliminary vacuum 30 minutes; pressure period 5 hours; final vacuum 10 minutes.

Liquids that are mobile or of low viscosity penetrate better, other things being equal, than more viscous liquids. Since temperature has such a pronounced effect on the viscosity of preservative oils and solutions it affects their ease of penetration into wood. High preservative temperatures give better absorptions and penetrations than low temperatures.

COAL-TAR CREOSOTE AND MIXTURES OF PETROLEUM OR TAR WITH CREOSOTE

Table 7 shows the effect of temperature on treatments of air-seasoned eastern hemlock ties with 100 percent coal-tar creosote, a 50–50 creosote-petroleum mixture, and a 90-percent petroleum and 10-percent creosote mixture. The preliminary vacuum, length of pressure period, and final vacuum were the same in all charges treated. With each pressure and preservative the only factor varied was the temperature of the preservative during the pressure period, which in turn varied the viscosity. Both the sapwood and heartwood of eastern hemlock are sufficiently resistant to prevent complete penetration under the conditions used.

In the treatments with creosote, increasing the temperature (lowering the viscosity) invariably increased the penetration and in most cases increased both the net and gross absorptions. Table 7 shows that a temperature of 180° F., which is a temperature that has been commonly used in commercial creosoting, gives much better results than 140° or 160°. Still better results were obtained, however, at the higher temperatures. In the treatments with the petroleum mixtures the penetration again was invariably greater at the higher temperatures but the absorptions were not so consistent. The absorptions and penetrations of the creosote were much greater than those for the more viscous petroleum mixtures.

In order to compare the relative effect of different viscosities of the same preservative, which are a function of temperature, the side penetrations and absorptions obtained with creosote at each temperature (table 7) have been averaged for the three pressures. These averages are given in table 8 and show the marked influence that temperature and viscosity changes have on penetration and absorption.

TABLE 8.—*Average [1] penetration and absorption of coal-tar creosote at 6 temperatures*

[Air-seasoned eastern hemlock ties]

Ties in average (number)	Preservative temperature	Absolute viscosity at temperature used in treatment	Average side penetration		Average net absorption per square foot of surface		Average gross absorption per square foot of surface	
	° F.	*Centipoises*	*Inches*	*Percent*	*Pounds*	*Percent*	*Pounds*	*Percent*
74	140	3.80	0.29	100	1.36	100	1.43	100
73	160	2.81	.39	135	1.78	131	1.89	132
73	180	2.22	.45	155	2.01	148	2.15	150
72	200	1.80	.51	176	2.27	167	2.54	178
72	220	1.50	.61	210	2.58	190	3.18	222
73	240	1.22	.67	231	2.61	192	3.85	269

[1] Data from table 7 averaged for pressures of 125, 150, and 175 pounds per square inch.

Since the treatments with coal-tar creosote were made at the same preservative temperatures with each of the three pressures, the general effect of pressure alone is indicated by averaging the results of the

six treatments made at different temperatures, for each pressure shown in table 7. This gives an average based on 140 to 149 ties for each pressure. A comparison of the results thus obtained shows that the average of side penetration and gross absorption varied approximately in proportion to the increase in gage pressure.

Figure 24, which is based on data from table 7, shows the penetrations obtained in the treatments made at 150 pounds pressure using the petroleum-creosote mixtures and creosote alone. With the viscosity near 8 centipoises a decrease of a few centipoises made but a slight change in the depth of side penetration, whereas a similar decrease in viscosity in the region of 3 or 2 centipoises made a marked

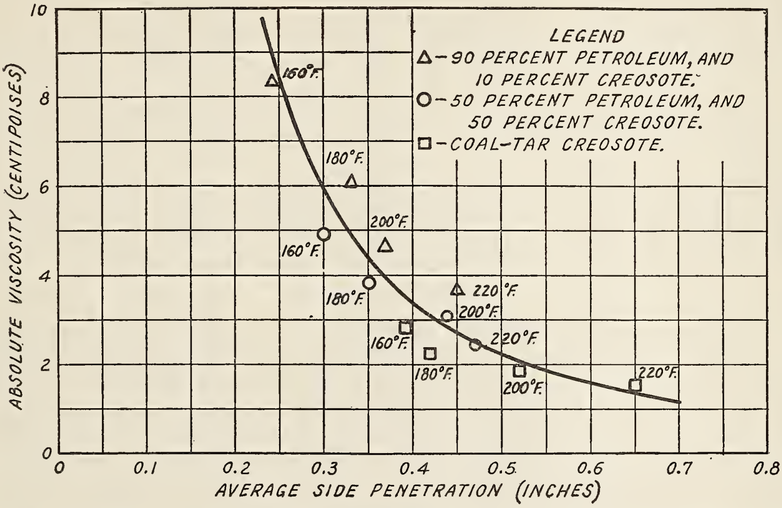

FIGURE 24.—Relation of absolute viscosity of preservative oils and penetration in air-seasoned eastern hemlock ties.

change in penetration. Figure 24 also indicates that better penetrations were obtained at the higher temperatures for similar viscosities in the mixtures used.

Figure 25 shows the effect of varying the viscosity without changing the temperature in a series of treatments of small, air-seasoned Douglas fir heartwood specimens with creosote and creosote mixtures. The specimens were matched in quality and four were used in each treatment. Three different petroleum oils were used in preparing the mixtures which contained creosote in the proportions of 75, 50, 30, and 10 percent, respectively. No preliminary or final vacuum was used, the treating temperature was kept at about 185° F., the treating pressure was about 125 pounds gage, and the pressure period was 2 hours. The results shown in the figure are averages. It is clearly evident that a distinct relation exists between the penetration and the viscosity.

Table 9 shows the effect of changing the temperature without changing the viscosity. The results, which were obtained by varying the temperature of different preservative oils so as to obtain the same absolute viscosity while the other treating conditions were held constant (*15*, *16*) indicate that temperature alone is a factor affecting treatment.

TABLE 9.—*Effect of changing temperature without changing viscosity in full-cell treatment* [1] *of air-seasoned eastern hemlock with creosote and creosote-petroleum mixtures*

Preservative	Specimens	Size of specimens	Viscosity	Pressure period	Treating temperature	Average net absorption per cubic foot	Average side penetration	Average longitudinal penetration
	Number	*Inches*	*Centipoises*	*Hours*	*° F.*	*Pounds*	*Inches*	*Inches*
Coal-tar creosote, grade 1	16	4 by 4 by 48	2.95	5	160	18.8	0.41	9.4
50 percent creosote and 50 percent petroleum oil	16	4 by 4 by 48	2.95	5	202	23.7	.46	10.7
10 percent creosote and 90 percent petroleum oil	16	4 by 4 by 48	2.95	5	235	20.6	.43	8.4
Coal-tar creosote, grade 1	19	3 by 4 by 47	2.81	3	160	19.4	.40	6.5
Mixtures of grade 1 coal-tar creosote and different proportions of a high-viscosity creosote	10	3 by 4 by 47	2.81	3	180	21.0	.36	6.2
	9	3 by 4 by 47	2.81	3	200	25.7	.44	7.3
	20	3 by 4 by 47	2.81	3	207	23.2	.40	7.1

[1] Treating conditions: Preliminary vacuum, 30 minutes; treating pressure, 150 pounds; final vacuum, 10 minutes.

Mixtures of coal tar and coal-tar creosote give results similar to those obtained with petroleum-creosote mixtures (*32*). The addition of coal tar to coal-tar creosote increases the resistance to penetration, depending both on the amount and the kind of tar added.

WATER SOLUTIONS

As shown in figure 23 the viscosity of a water solution is much lower than that of creosote and creosote mixtures and the viscosity of a water solution changes less with temperature variations. Nevertheless, the relatively small proportional change in viscosity of water solutions, which takes place with rising temperatures, apparently has a marked influence on penetration. Table 10 and figure 26 show the effect of viscosity and temperature of zinc-chloride solution on penetration in sawed specimens of coast-type Douglas fir. The viscosity of the solution was varied by changing the temperature and results were compared at four different pressures. Each charge contained 7 or 8 pieces 5 by 10 inches by 8 feet in size and the remainder 4 by 4 inches by 4 feet. At each pressure the same number and size of specimens were used and they were matched as well as possible against each other.

TABLE 10.—*Effect of viscosity and temperature of 3-percent zinc-chloride solution on penetration in sawed air-seasoned coast-type Douglas fir heartwood* [1]

Pressure (pounds per square inch)	Temperature of solution	Average side penetration		Average longitudinal penetration		Specimens in average [2]	Pressure (pounds per square inch)	Temperature of solution	Average side penetration		Average longitudinal penetration		Specimens in average [2]
	° F.	*In.*	*Pct.*	*In.*	*Pct.*	*Number*		*° F.*	*In.*	*Pct.*	*In.*	*Pct.*	*Number*
100	86	0.35	100	14.7	100	20	150	79	0.36	100	15.7	100	12
	120	.48	137	16.1	110	20		120	.52	144	17.4	111	12
	160	.60	171	17.0	116	20		160	.79	219	21.1	134	12
	200	.89	254	20.3	138	20		200	1.30	361	26.8	171	12
125	88	.36	100	16.4	100	13	175	83	.39	100	16.8	100	18
	120	.52	144	21.3	130	13		120	.65	167	17.1	102	18
	160	.67	186	19.8	121	13		160	.99	254	22.1	132	18
	200	.97	269	22.5	137	13		200	1.48	379	24.1	143	18

[1] All treatments had a preliminary vacuum 30 minutes and a pressure period 3 hours.
[2] Each treatment had 7 to 8 specimens 5 by 10 inches by 8 feet in size. Other specimens were 4 by 4 inches by 4 feet in size.

Table 10 shows a consistent increase in penetration as the temperature was increased; the greatest penetration was obtained at the highest temperature change. In other words, the 40-degree temperature change from 160° to 200° F. was more effective than a similar change between any two lower temperatures.

The relation between the absolute viscosity and the penetration obtained is expressed very closely by hyperbolic functions slightly different for each pressure. The empirical formulas with their respective curves are shown in figure 26. When plotted the actual values obtained in experiments coincided closely with the mathematical curves as may be noted by plotting the average penetration values given in table 10.

Figure 27 shows the effect of different pressures and temperatures on the gross and net absorptions of zinc chloride solution into Douglas fir. The increase in temperature always increased the gross absorption but at the two higher pressures the kick-back, upon releasing the pressure, was high in the charges treated at 200° F. This resulted in the net absorptions in these two charges being lower than in their companion 160° charges. As would be expected, however, the greater gross absorptions gave deeper penetrations despite the lower net absorptions.

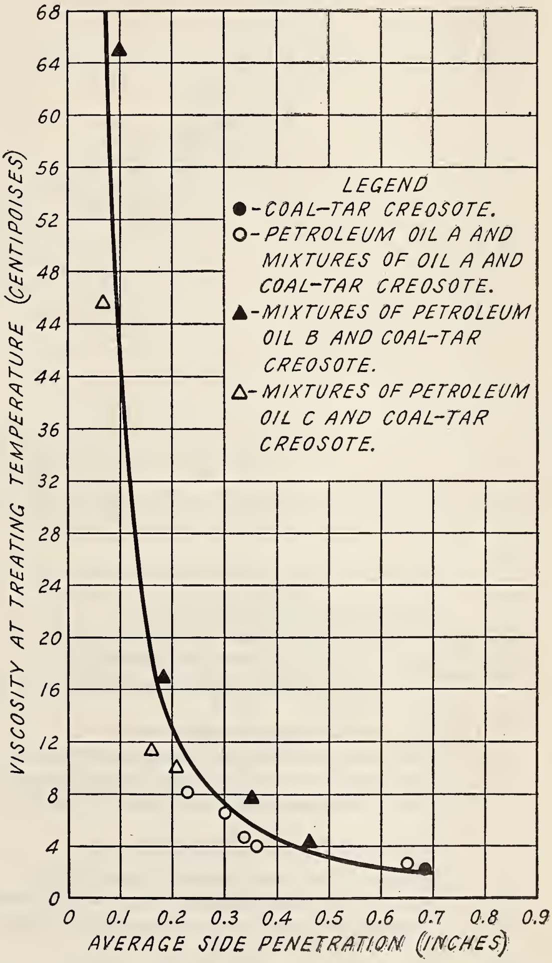

FIGURE 25.—Effect of varying viscosity (without changing temperature) upon the penetration of preservative oils in air-seasoned Douglas fir heartwood specimens.

Figure 28 shows the effect of different pressures and temperatures on the rate of absorption of zinc chloride solution in matched air-seasoned coast-type Douglas fir timbers during a 3-hour pressure period. The rate was notably slower at the lower temperatures and at the end of the 3-hour period the low temperature absorptions seemed to have more nearly reached a maximum. The slope of the curves

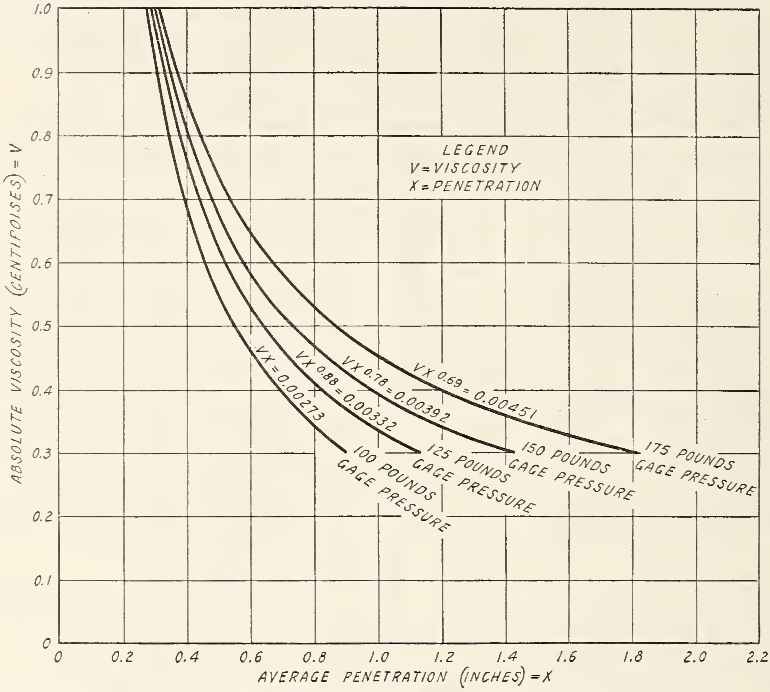

FIGURE 26.—Relation between absolute viscosity of zinc chloride solution and penetration in air-seasoned coast Douglas fir heartwood specimens.

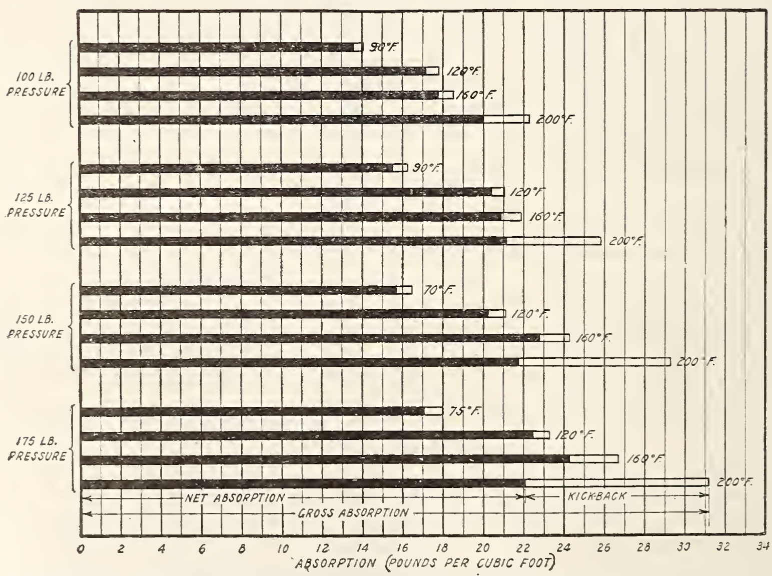

FIGURE 27.—Effect of different pressures and temperatures on gross and net absorptions of zinc chloride solution in air-seasoned, coast-type Douglas fir heartwood.

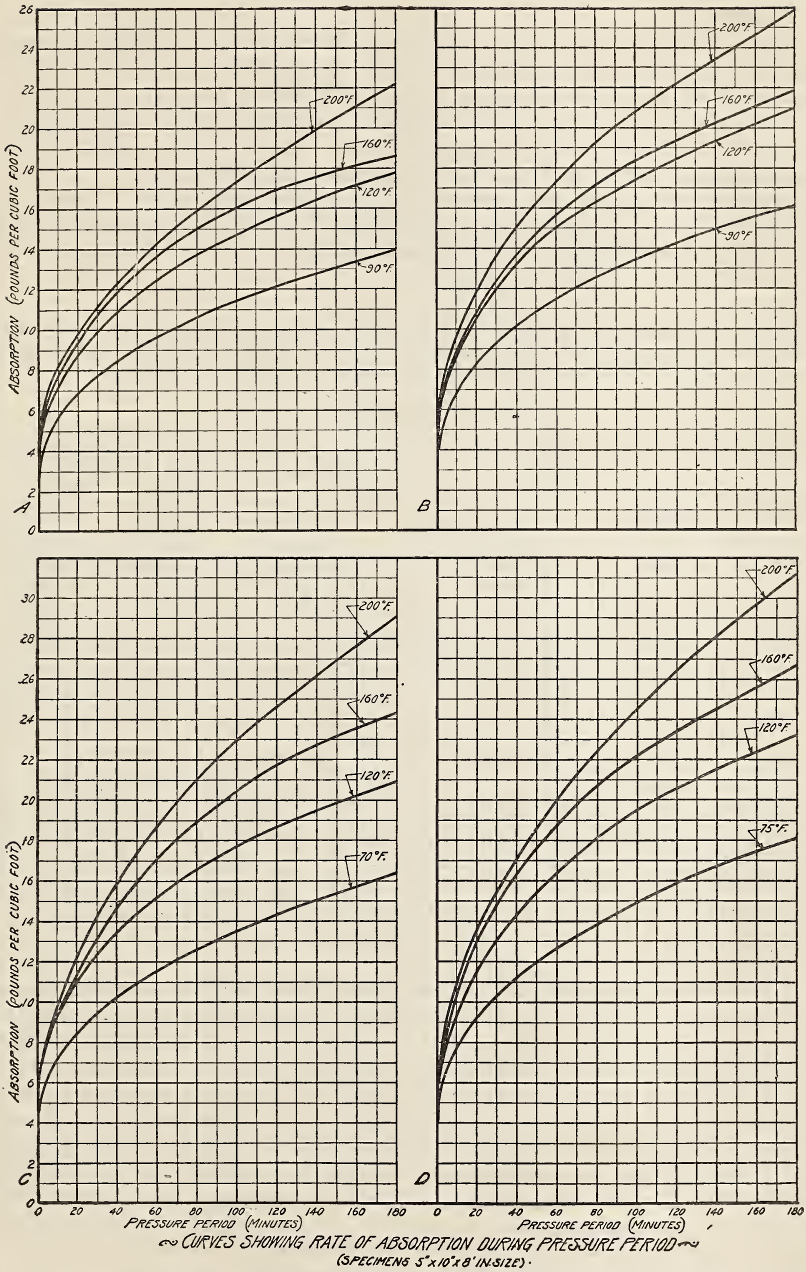

FIGURE 28.—Effect of different pressures and temperatures on the rate of absorption of zinc chloride solution in air-seasoned, coast-type Douglas fir heartwood timbers: *A*, treating pressure, 100 pounds; *B*, treating pressure, 125 pounds; *C*, treating pressure, 150 pounds; *D*, treating pressure, 175 pounds.

for the higher temperature indicates that the absorption could have been considerably increased if the pressure period had been continued.

Table 11 shows the results obtained in treatments of air-seasoned Rocky Mountain type Douglas fir ties using different solution temperatures in combination with different treating pressures. All ties were sawed transversely at the middle and lengthwise through the center for measurements of penetration. Most of the material was heartwood although a few of the ties had a small amount of sapwood. Penetration measurements were made on heartwood only. Although this wood is the same species botanically as the coast type Douglas fir, it is far more difficult to penetrate than the latter and is one of the most resistant of the native conifers.

TABLE 11.—*Results of treatments*[1] *on air-seasoned, sawed, Rocky Mountain type Douglas fir ties with zinc chloride solution when solution temperature and treating pressure were varied and treating period was kept constant at 3 hours*

[Ten ties in each treatment]

Treating pressure	Solution temperature	Average weight before treatment	Average net absorption		Average kickback	Average gross absorption		Average side penetration		Average longitudinal penetration	
			Amount	Increase over that obtained at lowest temperature		Amount	Increase over that obtained at lowest temperature	Depth	Increase over that obtained at lowest temperature	Depth	Increase over that obtained at lowest temperature
Lb. per sq. in.	° *F.*	*Lb. per cu. ft.*	*Lb. per cu. ft.*	*Percent*	*Lb. per cu. ft.*	*Lb. per cu. ft.*	*Percent*	*Inch*	*Percent*	*Inches*	*Percent*
50	80	33.6	5.2	--------	0.3	5.5	--------	0.11	--------	3.2	--------
	200	33.4	7.7	48	.5	8.2	49	.22	100	6.6	106
175	120	38.5	7.0	--------	.5	7.5	--------	.16	--------	6.7	--------
	160	33.9	10.3	47	.9	11.2	49	.30	88	9.5	42
	200	35.5	9.6	37	3.6	13.2	76	.31	94	10.0	49
200	120	32.1	8.4	--------	.7	9.1	--------	.25	--------	10.1	--------
	160	34.3	9.7	16	1.6	11.3	24	.30	20	12.5	24
	200	36.2	11.6	38	8.1	19.7	116	.33	32	14.0	39
225	95	36.9	6.4	--------	.5	6.9	--------	.15	--------	7.0	--------
	120	33.0	9.8	53	.7	10.5	52	.23	53	10.7	53
	160	35.6	10.2	59	1.6	11.8	71	.30	100	12.1	73
	200	34.3	14.9	133	11.0	25.9	275	.34	127	14.4	106
250	90	34.1	8.1	--------	.6	8.7	--------	.26	--------	10.0	--------
	120	36.8	9.4	16	.8	10.2	17	.25	--------	11.3	13
	160	36.9	10.5	30	1.5	12.0	38	.33	27	9.7	--------
	200	35.1	12.0	48	15.0	27.0	210	.60	131	15.6	56

[1] Preliminary vacuum 30 minutes at about 28 inches of mercury; no final vacuum.

The 3-hour pressure period used for the treatments outlined in table 11 was the same as that used in the treatments of coast-type Douglas fir (table 10). On account of the marked resistance of the Rocky Mountain type Douglas fir, however, this pressure period was too short to obtain appreciable penetrations except when the higher solution temperatures were used. As in the treatments made on coast-type Douglas fir, the results show that the solution temperature and viscosity had a very pronounced effect on absorption and penetration at all pressures, and that the effectiveness of the treating pressures was considerably increased at the higher temperatures. None of the ties showed collapse or checking except those in the treatment made at 200° F. and 250 pounds pressure.

Similar data for yellow birch and eastern hemlock are shown in table 12. The effect of temperature and viscosity on penetration is conspicuous in the results with each species although not so consistent

in every case as the results in table 10. A small amount of sapwood was present on some of the yellow birch ties and in making measurements of penetration an effort was made to eliminate all penetrations that might be in the sapwood.

TABLE 12.—*Effect of varying the temperature*[1] *of a 3-percent zinc chloride solution on the absorption and penetration in air seasoned yellow birch and eastern hemlock ties*

Species	Ties in treatment	Average weight before treatment	Pressure period	Treating temperature	Average net absorption		Average gross absorption		Average side penetration in heartwood		Absolute viscosity	
	Number	*Lb. per cu. ft.*	*Hours*	*°F.*	*Lb. per cu. ft.*	*Lb. per sq. ft. of surface*	*Lb. per cu. ft.*	*Lb. per sq. ft. of surface*	*Inch*	*Percent*	*Centipoises*	*Percent*
Yellow birch	25	46.6	4	140	22.1	3.0	22.6	3.1	0.32	100	0.54	100
	25	46.0	4	160	21.3	2.9	22.5	3.1	.38	119	.46	85
	25	46.3	4	180	22.6	3.1	24.4	3.3	.55	172	.39	72
	25	45.9	4	200	23.4	3.2	25.7	3.5	.75	234	.34	63
Eastern hemlock	25	30.3	4	160	19.6	2.8	20.6	3.0	.53	100	.46	100
	25	28.5	4	180	20.6	3.0	23.3	3.4	.69	130	.39	85
	24	28.6	4	200	23.0	3.3	28.6	4.1	.88	166	.34	74
	12	30.3	5	160	19.0	2.7	20.3	2.9	.71	100	.46	100
	25	30.6	5	200	18.5	2.7	25.8	3.7	.84	118	.34	74

[1] Preliminary vacuum 30 minutes at about 28 inches of mercury; treating pressure 150 pounds; no final vacuum.

From table 12 it may be noted that the absorptions in eastern hemlock ties treated with zinc chloride solution are somewhat higher in proportion to the penetration than those treated with preservative oils (table 7). This is probably on account of the deeper end absorption which occurs when water solutions are used and also on account of water solution being absorbed by the cell walls in the treated portion.

WOOD TEMPERATURES

The temperature at any point within the wood during treatment is a function of the original temperature of the wood, preservative temperature, heat conductivity of the wood, size and penetrability of the pieces under treatment, length of heating period, and perhaps other variables. The effect of any one variable is complicated by the other variables. Except with small pieces the length of the time the wood is exposed to the hot preservative is usually insufficient for the temperature at the center of the wood to approach closely the temperature of the surrounding preservative. This is true even in wood that is given a preliminary heating treatment, such as steaming or boiling under vacuum.

The temperature of wood that is resistant to treatment has an important influence upon the absorption and penetration. Wood at a lower temperature than that of the preservative will tend to cool the preservative as it penetrates and thus increase the viscosity. Pressure periods applied in the treatment of air-seasoned material are often too short to permit heating the wood to a favorable treating temperature.

PRESERVATIVE TEMPERATURES RECOMMENDED

Preservative temperatures of 190° to 200° F. can be used satisfactorily with oils or water solutions even for woods that are susceptible to injury during treatment. Temperatures somewhat higher than 200° can be used to advantage for species like southern yellow pine,

provided such temperatures are not applied too long and the pressure is so regulated that checking or collapse is avoided.

Where there is a tendency, in wood that is resistant to penetration, for severe checking or collapse to occur with a given temperature-pressure combination, the preservative temperature should be maintained at 190° to 200° F. and the pressure should be lowered until satisfactory results are obtained (*18*, *22*). With wood that is not resistant to treatment high preservative temperatures are not so necessary. High temperatures may also prove undesirable when injecting water solutions of preservatives into resinous wood because such temperatures may bring resin to the surface where it will interfere with painting or finishing if the wood is not resurfaced after treatment. It is a question in such cases whether it is better to accept the poorer penetrations and cleaner surfaces resulting from cold solutions or the resin exudation and the much better penetrations resulting from hot solutions. This difficulty does not arise with woods that do not exude resin. Preservative oils at the higher temperatures leave the wood cleaner after treatment than when lower treating temperatures are used.

High temperatures must not be used with some proprietary preservatives that are injected in water solution, for they will precipitate the preservative from its solution before it enters the wood. It is best to follow the recommendations of the proprietors as to temperature conditions when using such preservatives.

RELATIVE PENETRATION OF PRESERVATIVE OILS AND WATER SOLUTIONS

Table 13 gives the relative penetrations and absorptions of zinc chloride solution and coal-tar creosote obtained in two of the very refractory conifers. Similar results obtained in experiments with various other species show in a marked manner that resistant woods are considerably more difficult to penetrate with creosote and other oils than with water solutions. A still greater difference in the relative penetration of water solutions and preservative oil would have been shown with longer pressure periods than those used with the refractory species. Water solutions are absorbed within the cell walls while oils are absorbed only slightly in the cell walls under normal treating conditions. This may account for the superiority of penetration by water solutions as compared with oils of the same viscosity.

TABLE 13.—*Comparison of absorptions and penetrations with coal-tar creosote and zinc chloride solutions*

Species	Specimens	Preservative	Average weight before treatment	Treating pressure	Treating period [1]	Treating temperature	Average absorption		Average side penetration	
							Net	Gross	Heartwood	Sapwood
	Number		*Lb. per cu. ft.*	*Lb. per sq. in.*	*Hours*	° *F.*	*Lb. per cu ft.*	*Lb. per cu ft.*	*Inch*	*Inch*
Douglas fir:										
Rocky Mountain type [2].	8	Coal-tar creosote.	35.7	150	4	200	1.7	3.8	0.09	
Do	8	Zinc chloride solution.	35.6	150	4	180	15.8	20.5	.42	
Corkbark fir [3]	20	Coal-tar creosote.	25.0	100	5	180	9.1	10.4	.12	0.81
Do	20	Zinc chloride solution.	24.8	100	5	180	15.4	19.8	.28	.92

[1] Preliminary vacuum of about 28 inches applied for 30 minutes before pressure period. No final vacuum after pressure period.
[2] Air-seasoned specimens 4 by 4 by 48 inches in size.
[3] Sawed and hewed air-seasoned ties.

THE USE OF VACUUM

In both the steaming-and-vacuum and the Boulton or boiling-under-vacuum processes the function of the vacuum is to help remove moisture from green wood (pp. 32, 49). When seasoned timber is to be treated by a full-cell process a preliminary vacuum is used to remove as much air as practicable from the wood before admitting the preservative. With full-cell oil treatments a final vacuum is usually employed to recover some of the surplus oil from and near the surface of the wood and thus reduce the amount of dripping after removing the charge from the treating cylinder. A final vacuum is also used with water solutions for the same purpose but when the solutions are used at reasonably high treating temperatures the final vacuum is of little value for the surface of the wood dries quickly when the hot wood is withdrawn from the treating cylinder and as a result there is very little drip. With cold or cool solutions the drip after treatment is greater and the final vacuum is more useful. In the empty-cell treating processes a final vacuum is employed, after the release of pressure and withdrawal of preservative, for the purpose of hastening the expulsion of the surplus preservative by the expansion of the air imprisoned and compressed in the wood.

In employing a preliminary vacuum in full-cell treatments, since its purpose is to remove air from the wood, the air should not be readmitted by releasing the vacuum before filling the cylinder with preservative. Since the vacuum is not perfect there is always some air left in the cylinder. The resistance of the wood to the outward movement of the confined air also makes it impossible to remove more than a limited amount which will depend on the species, size of timber, whether sapwood or heartwood, moisture content, and other factors. As hot preservative is admitted to the bottom of the treating cylinder it warms the wood, driving out more air and this air, with that left in the space surrounding the wood, collects above the rising preservative. As the cylinder becomes nearly full of preservative the amount of air collected may be sufficient to release the vacuum entirely in the space above the preservative and a slight pressure may be produced. The amount of air that thus accumulates will, of course, be least with a high original vacuum.

This accumulation of air can be prevented by keeping the vacuum pump running during the filling process. Suction of preservative into the vacuum system during this period can be avoided by drawing the vacuum through a high inverted U pipe between the cylinder and the vacuum pump. Whether there is any advantage in continuing to operate the vacuum pump during the filling process has not been established by any known experimental evidence. If a high vacuum is first drawn it would seem that so little air could collect above the preservative that running the pump during the filling process would have a negligible effect but when a low initial vacuum is applied there might be a noticeable effect on the air pressure in the upper timbers in the charge. The temperature of the preservative when admitted to the cylinder will also affect the results. At higher temperatures more air will come out of the wood during the filling process and more vapors will be given off by the preservative. Certainly, however, if the surging of preservative into the vacuum system is prevented there can be no objection to keeping the pump running during the filling period.

Some specifications require that when air-seasoned wood is given a full-cell treatment the preliminary vacuum shall be held for a definite period after the maximum is reached. This seems to be an unnecessary requirement for after the maximum vacuum is reached it is probable that little if any additional air is removed. This is indicated by the fact that when there are no air leaks in the treating equipment the vacuum can usually be held without appreciable drop when the vacuum pump is stopped. In general, it should be sufficient to specify that the preliminary vacuum be applied until the maximum is obtained.

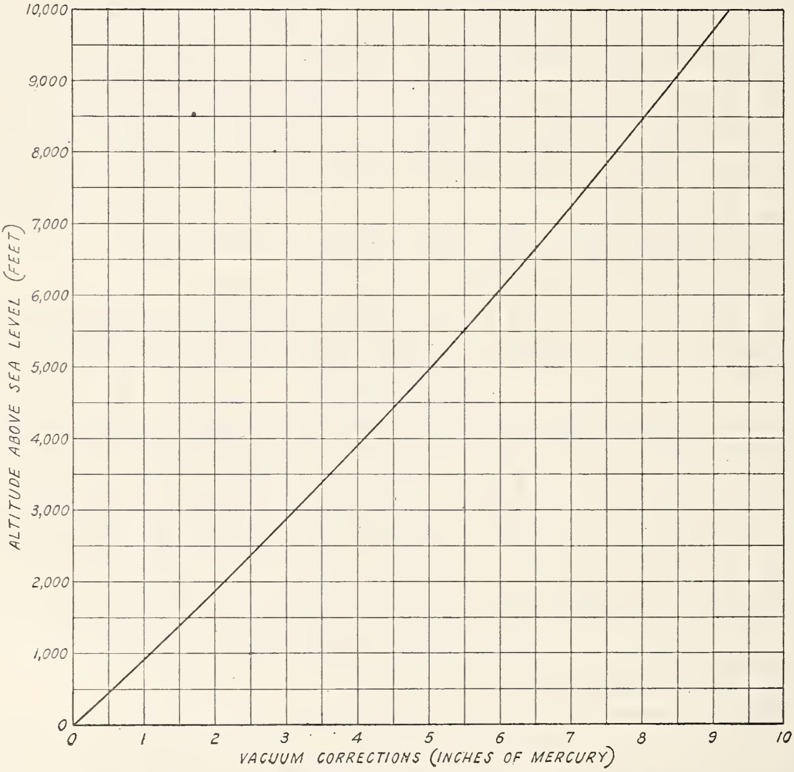

FIGURE 29.—Vacuum corrections corresponding with different altitudes. (Data from Smithsonian meteorological tables.)

When the vacuum is used after steaming or when the material is conditioned by the boiling-under-vacuum process (Boulton method) the air is removed more completely than when a vacuum is applied to cold, air-seasoned material. This is because the air in the cylinder can be more completely removed by the hot steam or vapors and because the air in the wood cells is expanded by the heat, making it possible to evacuate the cells more completely than when the timber is cold. In addition, air does not have an opportunity to fill the space originally occupied by the water which is removed under the vacuum. In air-seasoned material the space originally filled with water, except as reduced by shrinkage, is full of air at the time of treatment.

Treating specifications sometimes specify the minimum vacuum requirements for sea level and allow a correction to be made by plants

at higher elevations. This is commonly 22 inches, based on sea-level conditions. Figure 29 shows the vacuum correction in inches of mercury for different altitudes. The correction shown for any altitude is to be subtracted from the minimum vacuum specified for sea level in order to give the corresponding vacuum for that altitude. Figure 29, which is based on the standard barometric pressures for the different altitudes, does not take into account the daily variations in barometric pressure due to weather changes. Such a degree of refinement, however, is unnecessary in injecting preservatives into wood.

In using the steaming or the boiling-under-vacuum process at any plant above sea level it may be desirable to know the boiling points of water corresponding to different vacuums at that location. Figure 30 shows boiling points of water under different vacuums at sea

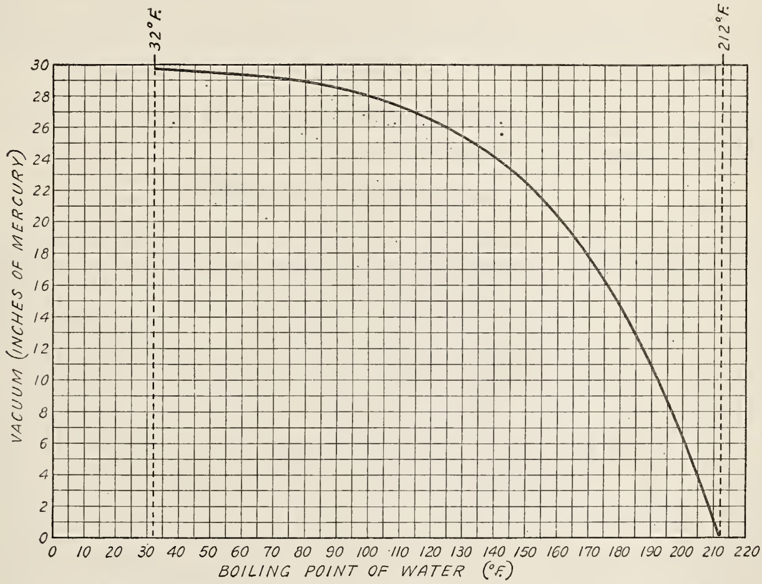

FIGURE 30.—Boiling points of water corresponding with different vacuums at sea level.

level. The vacuum required at a given altitude for a specified boiling point is equal to the vacuum required for that boiling point at sea level minus the vacuum correction for the altitude under consideration.

EXAMPLE OF THE USE OF FIGURES 29 AND 30

Green timber is conditioned by the Boulton process at a plant where the altitude is 5,000 feet. The temperature of the creosote is 185° F. What minimum vacuum will be required to reach the boiling point of water?

Figure 30 shows that at sea level a vacuum of about 13 inches is required to boil water at 185° F. The vacuum correction for an altitude of 5,000 feet (fig. 29) is approximately 5 inches of mercury. Therefore, the vacuum required at 5,000 feet altitude to boil water at 185° is 13 minus 5, or 8 inches of mercury.

The temperature at which water boils under atmospheric pressure at 5,000 feet altitude is the same as that at sea level when the vacuum is approximately 5 inches. Figure 30 shows this temperature to be about 203° F.

A curve, similar to figure 30 but corrected for the altitude of the individual plant, would answer directly the question given in the foregoing example.

With the Boulton process preservative temperatures higher than the boiling temperature of water corresponding with the maximum vacuum obtained should be used in order to overcome the resistance of the wood to moisture movement, to heat the wood more rapidly, and to compensate for the reduction in vacuum caused by the hydrostatic pressure of the preservative above the timbers.

Little experimental work has been done to determine the effect of the preliminary vacuum on the net absorption or the effect of the final vacuum on the recovery of preservative after the cylinder has been emptied of preservative. In commercial practice preliminary vacuums are commonly applied for 15 to 30 minutes when air-seasoned material is given a full-cell treatment. The longer period is more commonly used because specifications have frequently called for it. Final vacuums used with coast-type Douglas fir vary from about 1 to 4 hours but in most cases it is about 1½ to 2 hours. Final vacuums used on air-seasoned and steamed material of other species vary from about one-fourth to 2 hours with an average of about 1 hour.

The maximum vacuums usually obtained are about 22 to 26 inches of mercury based on conditions at sea level.

PRELIMINARY AIR PRESSURE

In the treatment of wood by the empty-cell processes no vacuum is used just before admitting the preservative; instead the preservative is forced into the timber against the back pressure of air in the wood. In the Lowry empty-cell process no artificial air pressure is used; only the air naturally within the wood when at atmospheric pressure is utilized. In the Rueping empty-cell process the preliminary air pressure is built up by forcing air into the treating cylinder and the wood before admitting the preservative. The Lowry and Rueping processes find wide application in the treatment of railway ties and poles and to a somewhat less extent in sawed timbers and land piling where heavier net absorptions are required. When the Boulton process is employed to condition the timber, before treatment by the empty-cell process, it is necessary to drain the cylinder when the vacuum period is completed. Air is then admitted at atmospheric pressure or at a higher pressure, depending upon whether the Lowry or Rueping method is used.

Most plants using the Rueping process for Douglas fir apply preliminary air pressures of 50 to 75 pounds which are held for one-half to 1 hour. Plants using the Rueping process for Rocky Mountain species generally apply preliminary air pressures of 50 to 80 pounds which are held for about one-half hour Most of the plants employing this process for southern yellow pine poles and piling and for hardwood ties, such as oak, gum, maple, birch, and beech, use air pressures of 50 to 75 pounds. Preliminary air pressures used in the Rueping process for southern yellow pine ties vary from about 65 to 100 pounds although a few plants use lower pressures of 30 to 60 pounds. Most of the plants treating southern yellow pine and hardwood timbers run the preservative into the cylinder as soon as the required air pressure is reached. The wide variations in the use of preliminary air pressure result in part from differences in the wood being treated and in part from lack of evidence as to what are the

most satisfactory air pressures and air-pressure periods for different requirements.

At the present time comparatively little is known about the rate at which air diffuses in the wood of different species or what the effect of moisture or intensity of pressure is on the transmission of air in the timber. Some preliminary laboratory experiments on the rate of air transmission across the grain were made on heartwood specimens of green Douglas fir. With an air pressure of 100 pounds a pressure period of more than 5 hours was required to obtain between 4 and 5 pounds gage pressure in a hole three-eighths of an inch in diameter, bored longitudinally, at a distance of about three-quarters of an inch from the surface. Under the same air-pressure conditions a pressure of less than 2½ pounds gage was obtained in 5 hours at a distance of about 1¾ inches from the surface. Changes occur more slowly and to a lesser depth in green than in seasoned timbers, provided checks do not affect the results.

Very little experimental work has been done to study the relation of preliminary air pressure to preservative pressure. It has been a commonly accepted view that in the empty-cell treatment the preservative pressure should be increased somewhat in proportion to the initial air pressure used. As an illustration, with timber to be treated at 150 pounds pressure by the full-cell process, the plant operator would probably apply 200 pounds preservative pressure after using a preliminary air pressure of 50 pounds, or 175 pounds preservative pressure after a 25-pound preliminary air pressure.

The difference between the preservative pressure and the initial air pressure does not necessarily represent the effective pressure forcing the preservative into the wood. Except for material that is very easily penetrated, such as the sapwood of various species or timbers of small dimension, the air pressure is not uniform throughout the timber. In resistant woods, subjected to preliminary air pressures, the intensity of air pressure in the wood may decrease rapidly and the air may penetrate only a short distance from the surface. Experiments on timbers of various refractory species showed that although a given preservative pressure may cause no checking or collapse when used in full-cell treatments or when no preliminary air or vacuum is employed, severe checking and collapse may occur if an initial air pressure is used and the preservative pressure is increased by an amount equal to the initial air pressure. This general practice, therefore, is not safe to follow but rather the amount of increase in preservative pressure needed should be worked out by experience and observation at each plant.

PRESERVATIVE PRESSURE

At some plants the maximum preservative pressure is applied as soon as it can be reached, whereas at others it is applied gradually, reaching the maximum in from one-half to 2 hours, depending on the kind of material and species treated. When pressures of 200 pounds or greater are used they are generally approached gradually during the entire pressure period so that the average pressure is considerably less than the maximum. No study has been made, so far as is known, to determine the relative merits of applying pressure gradually in comparison with a constant pressure applied over the entire pres-

sure period. Possibly plants using pressures gradually raised to a relatively high maximum could obtain similar results if the average pressure or even one somewhat lower than the average were maintained during the entire pressure period.

Resistance of the wood to the transmission of liquids and gases necessarily makes the effectiveness of the preservative pressure decrease as the depth of penetration increases. This effect may be noted in sawed timbers or pole ties where both sapwood and heartwood faces are exposed. Penetration is, of course, deeper in the exposed heartwood faces than in the heartwood covered by the sapwood since the resistance of the sapwood reduces the effect of pressure on the heartwood beneath it.

In the discussion relating to the effect of preservative temperature attention has been directed to the fact that the treating pressure must be carefully controlled when the timber shows evidence of checking or collapse under the treating conditions employed. Higher treating pressures can be used on seasoned wood than on wood that is green or that has been heated for a long time.

PRESSURE PERIOD

The length of pressure period required to obtain a given absorption depends largely upon the ease with which the timber can be impregnated and upon the treating conditions employed. In the treatment of resistant material the pressure period should be long enough to obtain the maximum benefit of the pressure employed and to allow sufficient heating of the wood to produce favorable conditions for treatment. Attempting to shorten the treating period by the use of high pressures frequently results in erratic penetrations or unsatisfactory absorptions. Treatment is sometimes discontinued when the rate of absorption becomes slow and it is assumed nothing much can be gained by using a longer pressure period. In some cases the slow rate of absorption is because the wood has not had time to become heated so that the best penetration can be obtained. Experiments have shown that better penetrations are usually obtained with moderate treating pressures and moderately long pressure periods than by very high pressures for short periods. On the other hand, little is to be gained by holding the pressure after absorption has practically ceased and, from the standpoint of treating costs, a reasonable balance must be established between treating time and treating pressure.

A few plants treating resistant woods preheat the charge in the hot preservative for a time before applying pressure. Whether this is as effective as applying pressure from the start, thereby obtaining a longer pressure period without increasing the total time of treatment, is a question on which there is some disagreement of opinion. When pressure is applied the preservative helps carry heat into the wood as it penetrates. It therefore appears that an advantage would be gained by applying pressure as soon as possible after the cylinder is filled with the preservative, in order to help increase the rate of heating and also to have the benefit of a longer pressure period. So far as is known, however, no definite data have been obtained on this subject.

The pressure periods required for Douglas fir timbers that have been conditioned by the Boulton process are, in general, considerably shorter than are required to obtain a similar treatment in air-seasoned

wood. The Boulton-processed wood has a higher initial temperature at the beginning of the pressure period than seasoned wood that has not been heated and this is apparently of considerable assistance in reducing the length of the pressure period.

It has been observed in experiments on air-seasoned wood in which different pressure periods were employed that the tendency for checking and collapse to occur increased as the length of the pressure period increased, other treating conditions being constant. In such cases the difficulty was overcome by lowering the treating pressure and when necessary, using a longer pressure period to compensate for the lower pressure.

Results of treatments made on Rocky Mountain type Douglas fir ties with pressure and treating period varied and solution temperature constant (table 14) show that the penetrations and absorptions were very much better in 6- and 8-hour treatments than in those made using pressure periods of 2 and 4 hours. In general, an increase of 2 hours in the pressure period gave better results than an increase of 50 pounds in pressure with treating period constant. A solution temperature of 175° F. was used in these tests so that a wider range of pressure could be used in the study of the relative effect of pressure and pressure period. If a higher solution temperature had been used it would have been necessary to use lower pressures to avoid collapse and checking. All ties excepting those in the 4- and 6-hour treatments at 250 pounds pressure were apparently uninjured by the treating conditions used. About half of those in the 4-hour treatment at 250 pounds pressure showed considerable collapse and checking and all of those in the 6-hour treatment at this pressure were badly injured by collapse and internal checking. These results show that both the pressure and length of pressure period affected the condition of the timber.

TABLE 14.—*Results of treatments* [1] *on air-seasoned, sawed, Rocky Mountain type Douglas fir ties with 3-percent zinc chloride solution when treating period and treating pressure were varied and temperature was kept constant at 175° F.*

[10 ties in each treatment]

Treatment no.	Treating pressure	Treating period	Average weight before treatment	Average net absorption		Average kickback	Average gross absorption		Average side penetration		Average longitudinal penetration	
				Amount	Increase over that in 2-hour treatment		Amount	Increase over that in 2-hour treatment	Depth	Increase over that in 2-hour treatment	Depth	Increase over that in 2-hour treatment
	Lb. per sq. in.	*Hours*	*Lb. per cu. ft.*	*Lb. per cu. ft.*	*Percent*	*Lb. per cu. ft.*	*Lb. per cu. ft.*	*Percent*	*Inch*	*Percent*	*Inches*	*Percent*
1	100	2	33.5	5.5	-------	0.4	5.9	-------	0.20	-------	6.8	-------
2	100	4	36.8	7.8	42	.3	8.1	37	.20	0	8.8	29
3	100	6	34.4	10.2	85	.5	10.7	81	.29	45	13.0	91
4	100	8	33.1	11.5	109	.5	12.0	103	.32	60	15.9	134
5	150	2	33.2	8.4	-------	.6	9.0	-------	.25	-------	10.5	-------
6	150	4	36.0	9.6	14	.8	10.4	16	.25	0	9.5	-------
7	150	6	35.0	14.2	69	1.3	15.5	72	.27	8	16.1	53
8	150	8	33.5	15.0	79	2.1	17.1	90	.38	52	18.2	73
9	200	2	33.8	9.1	-------	2.4	11.5	-------	.25	-------	9.8	-------
10	200	4	32.8	11.5	26	4.2	15.7	37	.31	24	16.9	72
11	200	6	36.7	13.5	48	3.9	17.4	51	.39	56	17.0	73
12	250	2	33.7	8.9	-------	5.2	14.1	-------	.20	-------	13.4	-------
13	250	4	32.9	13.3	49	10.2	23.5	67	.34	70	19.4	45
14	250	6	33.1	16.0	80	11.2	27.2	93	.41	105	30.0	124

[1] Preliminary vacuum 30 minutes at about 28 inches of mercury; no final vacuum.

KICK-BACK

When the pressure is released at the end of the pressure period some of the preservative flows out of the wood and the treating cylinder and returns to the working tank. The quantity of preservative that flows back into the tank is called the "kick-back." The total quantity of preservative injected into the wood during the treating operation is called the "gross absorption." In other words, the gross absorption includes the amount of preservative absorbed by the wood while the cylinder is being filled as well as that injected during the pressure period. The difference between the gross absorption and the kick-back plus the preservative recovered during the final vacuum gives the net absorption.

The most important factor causing kick-back under moderate pressure conditions is the expansion of air compressed in the wood during the pressure period. The outstanding characteristic of the empty-cell processes, as distinguished from the full-cell, is that a larger proportion of the gross absorption is expelled by the imprisoned air after the pressure period. This expulsion usually permits reasonably large gross absorptions and deep penetrations with comparatively small net absorptions. The net retention, however, may vary widely for any particular gross absorption, depending within certain limits on initial air pressure, species, whether sapwood or heartwood, moisture content, and other variables. As the preservative is forced into the wood during the empty-cell treatment some of the confined air becomes mixed with the preservative, although when penetration is not complete some of the air must obviously occupy space in the untreated portion. It is probable that the air in the wood cells that are partly filled with preservative is largely responsible for the kick-back. A proof that small air bubbles must be trapped in the preservative is shown in the empty-cell treatment of sapwood material and of other easily treated material which takes complete penetration. If the air were merely compressed and forced further into the timber it would not be practical to penetrate the wood completely in the region occupied by the entrapped air.

Another factor that influences the kick-back, depending on the material and treating conditions employed, is the compression of the wood during the pressure period and its expansion upon release of pressure. This effect is greatest with woods that are resistant to treatment, especially if they are of low compressive strength, and when the timber is conditioned by the steaming or Boulton process. When the Boulton process is used the wood has a high moisture content and is well heated so that it is more pliable when pressure is applied. The tendency of the wood to compress is naturally greater with high treating pressures and long treating periods. In experiments conducted at the Forest Products Laboratory on ties of low density and high resistance to penetration the ties practically recovered their normal volume when pressure was released immediately after treatment. Similar ties when held under a pressure that gradually dropped from 150 to 125 pounds while the preservative cooled, showed a permanent reduction of 6 to 7 percent of the original volume. A combination of high temperature and high pressure is likely to cause considerable permanent reduction in volume, accompanied by checking and collapse. The kick-back resulting from compression of the

wood has often been overlooked in treating practice. This compression of the wood will also indicate a higher gross absorption than is actually obtained. A charge of timber on which a high treating pressure is used may appear to have a much higher gross absorption than another charge treated under a lower pressure, yet the true gross absorption may be greater in the case where the lower pressure is used. When this is not recognized the treating-plant operator may believe that he is obtaining a high kick-back and a correspondingly high gross absorption while the actual kick-back of preservative from the wood cells may be much less than that indicated. Unfortunately, there is no way in which the kick-back caused by compression of the wood can be determined. Kick-back is less in timbers having a high moisture content as might be expected since the amount of air in the wood decreases as the amount of water increases. The relation of air volume and moisture content is shown in figure 8. An approximate determination of the maximum amount of preservative that can be absorbed in the available air space of the treated wood (p. 22) will help in finding whether kick-back is partly caused by compression of the wood.

Increasing the preservative temperature, the treating pressure, or the length of the pressure period also increases the amount of kick-back. The effect of temperature and pressure on kick-back is shown in figure 27 and also by the data given in tables 7, 8, 11, and 12.

From table 14 it may be noted, by comparing the results obtained at each pressure, that the general effect of increasing the pressure period was to increase the kick-back. This is indicated by comparing the averages of all the 2-, 4-, and 6-hour periods, respectively.

There is naturally a large variation in the relative penetrability of different woods and kick-back caused by expansion of compressed air in the wood will be less from resistant timbers than from sapwood material or from species that are more pervious to the passage of air and liquids. In empty-cell treatments of air-seasoned southern yellow pine timbers that are largely sapwood the kick-back often amounts to a large proportion of the gross absorption but it is usually much less in material that is largely heartwood.

Even when the full-cell process is employed there is always a certain amount of kick-back because more or less air is left in the wood after the preliminary vacuum is applied. This kick-back will be greater from air-seasoned timbers on which the preliminary vacuum is applied when the charge is cold.

In experimental full-cell treatments on air-seasoned ties of different species containing a considerable amount of sapwood, the kick-back varied from about 4 to 10 percent whereas for ties of resistant woods the kick-back varied from about 6 to 25 percent of the gross absorption. This higher kick-back from the resistant woods was partly caused by compression of the timber under the treating conditions employed. Preservative oils were used in these treatments. The kick-back was somewhat higher for similar treating conditions when zinc chloride solution was used.

The final vacuum is usually of more assistance in removing excess preservative when an empty-cell process is employed than when the timber is given a full-cell treatment. In general, the final vacuum is held only a sufficient length of time to prevent appreciable dripping of the preservative after the timbers are removed from the cylinder.

ABSORPTION AND PENETRATION

The effectiveness of treatment depends on both the depth of penetration and the absorption obtained. Absorption alone cannot be taken as a measure of effectiveness for there may be considerable differences in penetration and distribution of preservative in different timbers or different charges having the same absorption. Absorptions are most nearly comparable when the treating conditions are similar and the timbers are of the same size, character, sapwood content, and degree of seasoning.

The following are some of the more important reasons why the absorption does not necessarily indicate whether the wood has been properly treated:

1. The treating conditions may be controlled, as in the empty-cell processes, so that a large gross absorption and consequently a deep penetration is obtained with subsequent recovery of a considerable proportion of the original or gross absorption. On the other hand, treating conditions may be used where only a small amount of kick-back occurs, such as in the full-cell process, and a much heavier net absorption is required to obtain an equally good penetration.
2. Some woods take a deep end penetration and very small side penetration while in others the ratio of end to side penetration is not so high. In the first case the absorption may be largely at the ends of the timbers, particularly when they are fairly short and the end-surface area is large in proportion to the side-surface area.
3. When the timbers in a charge have varying amounts of sapwood and heartwood, or are of mixed species which vary widely in their relative resistance to treatment, the more easily treated sapwood or more easily treated species may absorb a disproportionate amount of the average absorption indicated for the charge.
4. Timbers that have not had fairly uniform seasoning may take heavy absorptions and deep penetrations in some portions and have poor treatment in other portions.
5. In timbers that vary considerably in size and in those that cannot be completely penetrated, the penetration for a given absorption is greatly influenced by differences in ratio of surface area to volume (p. 8).

Penetration is more nearly a measure of effectiveness of treatment than is absorption but with the same penetration higher absorption indicates better treatment because of the greater concentration of preservative in the wood. The gross absorption is also a better indication of treatment than the net absorption because good gross absorptions are necessary to obtain satisfactory penetrations.

FULL-CELL AND EMPTY-CELL ABSORPTIONS

In the empty-cell treatment of poles of southern yellow pine, which in the more commonly used sizes are largely sapwood, the net retention of preservative varies from about 25 to 75 percent of the gross absorption depending on the air pressure in the wood, the character and condition of the timber, and other factors. With an 8-pound empty-cell treatment and an average net retention of 50 percent, the gross absorption would be 16 pounds per cubic foot. If a full-cell

treatment of 12 pounds were applied, the kick-back would need to be about 25 percent of the gross absorption or 4 pounds per cubic foot for the same gross absorption as that obtained in an 8-pound empty-cell treatment. This kick-back, however, is considerably higher than would ordinarily be obtained with a full-cell treatment of such timbers. As deep penetrations with a full-cell treatment of 12 pounds as with an 8-pound empty-cell treatment should therefore not be expected.

Figure 31 shows the relation observed between penetration and absorption in air-seasoned, sawed, eastern hemlock ties treated with preservative oils by the full-cell process. In this figure the individual ties in various treatments are grouped according to differences of 0.1-inch penetration. All ties having from 0 to 0.1-inch penetration

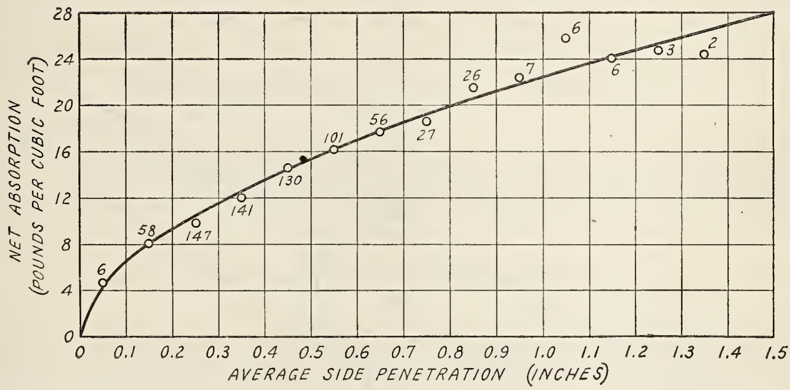

FIGURE 31.—Relation observed between penetration and absorption of preservative oils in air-seasoned eastern hemlock ties treated by full-cell process. (Numbers opposite the points indicate the number of ties averaged in the group. The ties were grouped for differences of 0.1-inch penetration.)

are the first group. The average gross absorption obtained in the treatments was about 2 pounds greater than the net absorption.

RELATION OF DIMENSIONS OF TIMBER TO ABSORPTION AND PENETRATION

HEARTWOOD TIMBERS

For many years preservative treatment was largely confined to crossties and larger material. Since ties do not vary widely in dimensions the volumetric absorptions necessary to give satisfactory results with timbers of this kind have been fairly well established from experience. In recent years, however, the application of preservative treatment has been extended to many different types of timber having widely different cross-sectional dimensions. The tendency of purchasers is to specify the same absorptions regardless of dimensions. If all of the wood could be penetrated the dimensions would not need consideration and comparable treatments could be obtained with absorptions based on the volume of the timber. Very few species, however, are sufficiently permeable in the heartwood to permit complete penetration even when the timbers have relatively small

cross-sectional dimensions. In large timbers the ratio of surface area to volume is much smaller than in pieces of small dimensions. Since there is less surface area per cubic foot in the large timbers than in small ones a given quantity of preservative can penetrate deeper in the larger sizes for the same absorption per unit volume.

The following example will illustrate the disparity in treatment that may result if the same absorption is specified for heartwood timbers having the same volume but different surface areas. Assume a 7 by 9 inch by 8-foot heartwood tie is to be treated with a net retention of preservative of 8 pounds per cubic foot. A tie of this size will have a volume of 3½ cubic feet and a total surface area of

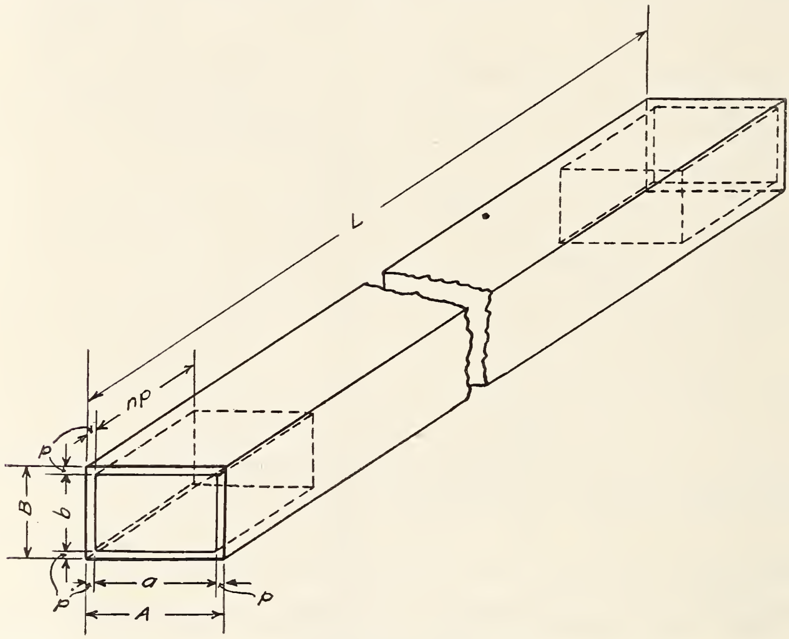

FIGURE 32.—Relation of surface area and amount of wood impregnated in a sawed heartwood timber.

about 22.2 square feet or about 6.35 square feet per cubic foot. If the same timber should be cut into four pieces 3½ by 4½ inches by 8 feet in size the volume would still be the same but the total surface area would be 43.54 square feet or about 12.4 square feet per cubic foot. This is an increase of about 96 percent in surface area over that of the tie. Naturally the 8 pounds of preservative will penetrate deeper when injected through 6.35 square feet of surface than when the same amount of preservative is used for 12.4 square feet of surface.

If the average ratio of end to side penetration were determined it would be possible to compute what might be called an "equivalent" side-surface area for a given size of timber. With this equivalent side-surface area known it would be a simple matter to specify volumetric absorptions that should give similar penetrations in timbers having different dimensions. For example, in figure 32 let

the average end penetration be n times as deep as the average side penetration p. It can be seen that 1 square foot of end surface would require the same quantity of preservative as n square feet of side surface, assuming the preservative equally concentrated in the treated portion.

From figure 32 it may be noted that the total equivalent surface area to be impregnated in a given sawed timber is $(2\,AL+2bL+2nab)$ square feet of side surface area when the linear dimensions are in feet or

$$\left[L\left(\frac{A+b}{6}\right)+\frac{nab}{72}\right]$$

when the length L is in feet and the other dimensions are in inches. The volume of treated wood in cubic feet is therefore

$$(2AL+2bL+2nab)\frac{p}{12}=\left[ABL-ab\left(L-\frac{np}{6}\right)\right]$$

where p, the penetration, is in inches and the other dimensions are in feet. If W is the absorption in pounds per square foot of equivalent surface area and T the total weight of preservative in the timber, then

$$T=\frac{W}{6}\left[L(A+B-2p)+\frac{n}{12}(A-2p)(B-2p)\right]$$

when L is in feet and A, B, and p are in inches. Similarly, the absorption in pounds per cubic foot is T divided by the volume of the timber, expressed in cubic feet.

The average side and longitudinal penetrations have been measured in a large number of air-seasoned heartwood specimens of several different woods, such as southern pine and Douglas fir, which take only a limited penetration (*20*, *21*). In general, the longitudinal penetration of creosote was found to be from 10 to 20 times as deep as the side penetration and from 15 to 25 times as deep when the preservative was zinc chloride solution. Table 15 has been prepared to serve as a guide in specifying absorptions for heartwood timbers and shows the approximate amount by which volumetric absorption should be increased or decreased to give a treatment equivalent to that obtained in a 7- by 9-inch by 8-foot timber. This timber of tie size is taken as a standard for the comparison of absorptions in timbers of other dimensions since the necessary volumetric absorptions for ties are better known than for timbers of any other size.

TABLE 15.—*Amount by which volumetric absorptions in various sizes of timber should be increased or decreased to give a treatment equivalent to that obtained with a given absorption in a 7- by 9-inch by 8-foot timber*

[For heartwood timbers or those which contain only a small amount of sapwood]

Nominal cross section (inches)	Length (feet)	Increase or decrease in absorption[1] for preservative oils	Increase or decrease in absorption[2] for water solutions	Nominal cross section (inches)	Length (feet)	Increase or decrease in absorption[1] for preservative oils	Increase or decrease in absorption[2] for water solutions
		Percent[3]	*Percent*[3]			*Percent*[3]	*Percent*[3]
2 by 4	All lengths[4]	+74	+56	8 by 8	4	+33	+40
2 by 6	do	+64	+48		8	−1	0
2 by 8	do	+58	+42		12	−12	−14
2 by 12	do	+51	+36		16	−18	−21
3 by 6	4	+73	+70	8 by 12	4	+26	+34
	8	+49	+41		8	−10	−8
	12	+41	+32		12	−21	−22
	16	+37	+27		16	−27	−29
3 by 10	4	+65	+64	8 by 16	4	+22	+32
	8	+38	+33		8	−14	−12
	12	+30	+22		12	−26	−26
	16	+25	+17		16	−32	−33
4 by 4	4	+72	+70	10 by 12	4	+21	+31
	8	+47	+40		8	−15	−12
	12	+39	+30		12	−27	−27
	16	+35	+25		16	−33	−34
4 by 8	4	+54	+56	10 by 16	4	+18	+28
	8	+26	+21		8	−19	−16
	12	+16	+10		12	−32	−31
	16	+11	+4		16	−38	−38
4 by 12	4	+48	+51	12 by 14	4	+16	+27
	8	+18	+15		8	−21	−18
	12	+8	+3		12	−34	−33
	16	+3	−3		16	−40	−40
6 by 8	4	+40	+45	14 by 14	4	+14	+25
	8	+8	+7		8	−24	−20
	12	−3	−6		12	−36	−35
	16	−8	−12		16	−42	−43
6 by 12	4	+33	+40	16 by 16	4	+11	+23
	8	0	0		8	−28	−23
	12	−12	−14		12	−40	−39
	16	−17	−20		16	−47	−46
6 by 16	4	+30	+37				
	8	−5	−4				
	12	−16	−18				
	16	−22	−24				

[1] Unit end absorption assumed to be 15 times unit side absorption.
[2] Unit end absorption assumed to be 20 times unit side absorption.
[3] Plus sign indicates increase; minus sign indicates decrease.
[4] End absorption in timbers 2 inches thick is negligible.

Many measurements of the average side penetration in heartwood timbers of the commonly treated species indicate that a fair average value for general conditions would be about one-half inch. The computations for table 15 were therefore made on the assumption that the values for the ratio of end to side penetrations are 15 and 20, respectively, for preservative oils and water solutions, and the penetration is one-half inch. These values should give results that are reasonably close and will apply to treatment with either the full-cell or empty-cell processes since the same gross absorption obtained by either process should give similar penetrations. Table 15 includes a variety of sizes so that a close estimate can be made for intermediate dimensions.

With the foregoing ratios of end to side penetration ($n=15$ and 20, respectively, for creosote and water solutions) and the average side penetration assumed as one-half inch, the "equivalent" surface area of a 7- by 9-inch by 8-foot tie is about 30 square feet when treated with a preservative oil and about 33.3 square feet when treated with water solutions. On this basis the volume of treated wood in the tie is about

1.25 cubic feet for preservative oils and 1.4 cubic feet for water solutions. With the penetrations as assumed, about 36 percent of the total volume of a heartwood tie, having an average side penetration of one-half inch, would then be treated with preservative oils and about 40 percent of the volume would be treated when water solutions were used.

MIXED SIZES IN A CHARGE OF HEARTWOOD TIMBERS

If a charge of heartwood timber contains pieces of different dimensions but of the same species and similar moisture content, the larger sizes will naturally absorb less than the average volumetric absorption specified while the smaller sizes will take a heavier absorption. Theoretically the penetration would be the same in all timbers, assuming equal resistance to treatment. If it is necessary to treat more than one size of timber in a charge the approximate proportional absorption should be determined for all timbers of each size. The total absorption for the charge will then be the sum of the absorptions required for the material in each group.

EXAMPLE OF COMPUTATION OF ABSORPTION IN MIXED SIZES IN A CHARGE OF HEARTWOOD TIMBERS

A charge has approximately 1,500 cubic feet of timbers 4 by 8 inches by 16 feet in size and 1,000 cubic feet of 10- by 12-inch by 16-foot timbers. All are to be treated with a net retention of creosote equivalent in penetration to an 8-pound-per-cubic-foot treatment in a tie. What is the total absorption for the charge?

From table 15 it is found that the 4- by 8-inch by 16-foot timbers should have about 111 percent of the absorption required for the tie or 8.9 pounds per cubic foot. Similarly the 10- by 12-inch by 16-foot timbers should have 67 percent of the 8-pound absorption or about 5.4 pounds per cubic foot. The total absorption to be specified for the charge would then be $8.9 \times 1{,}500 + 5.4 \times 1{,}000 = 18{,}750$ pounds, or an average absorption of about 7.5 pounds per cubic foot. An 8-pound absorption in such a mixed charge should be better than would be expected from an 8-pound treatment in ties. If the small-sized pieces constituted a much higher proportion of the total volume, calculation would show it desirable to specify an average absorption of somewhat more than 8 pounds per cubic foot.

SAPWOOD TIMBERS AND EASILY TREATED WOODS

Timbers that have fairly easily penetrated heartwood, that are practically all sapwood, or that contain a large proportion of sapwood, should have heavier volumetric absorptions than heartwood timbers that take only a small penetration. If the proportion of treated wood in a heartwood tie is assumed as approximately 36 percent when impregnated with preservative oils and 40 percent when water solutions are used, then in order to obtain the same concentration of preservative per unit volume of treated wood in a timber that can be completely penetrated the volumetric absorption should be increased by an amount equal to $\frac{1}{0.36}$ or about 2.8 times when treated with a preservative oil and by $\frac{1}{0.4}$ or about 2.5 times when treated with a water solution. In most cases, however, the same concentration would not be necessary or justified although some increase would be desirable over the absorption required in heartwood timbers. There is evidence from service-test records to show that a given absorption which may be found satisfactory for heartwood timbers may be entirely inadequate for similar material that is largely sapwood or that

can be fairly easily penetrated in both the heartwood and sapwood portion. For example, a large proportion of a group of experimental ties of red oak, sapwood gum, and sapwood southern yellow pine treated by the empty-cell method with 5 to 6 pounds coal-tar creosote per cubic foot were badly decayed after 7 years' service. Other ties in the same group and of the same species that had a net retention of about 12 pounds of creosote per cubic foot showed no signs of decay within the same period. These ties were installed in the South where conditions are particularly favorable to decay. Under similar service conditions the lower absorptions have been considered satisfactory for heartwood ties.

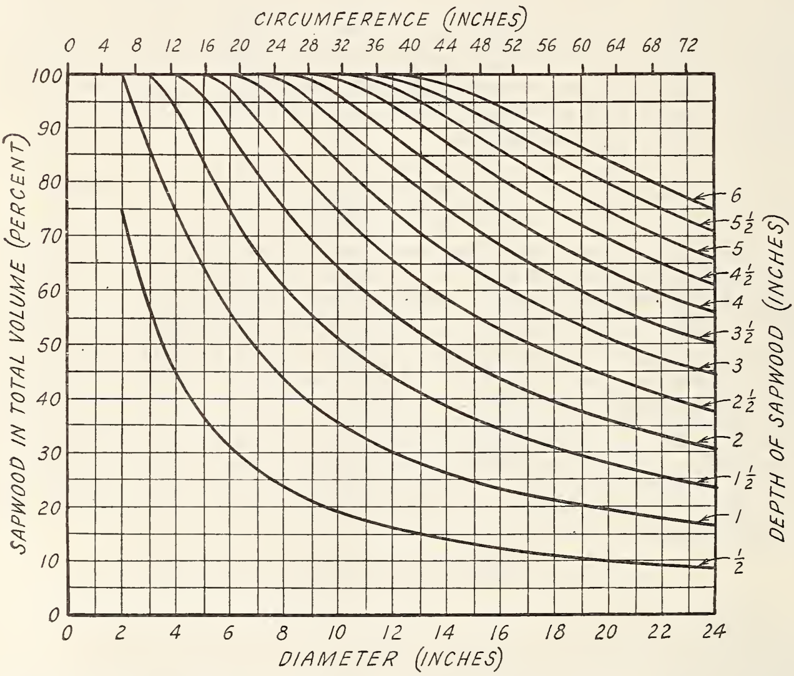

FIGURE 33.—Percentage of sapwood in timbers of various diameters having different depths of sapwood.

A discussion of absorptions recommended for sapwood timbers will be found on page 108.

In round timbers such as poles and piling the end surface area is so small a percentage of the total surface area that the influence of end absorption is generally negligible and only in exceptional cases is it practical to penetrate much more than the sapwood.

Figure 33 shows the relation between the percentage of sapwood in the total volume of round timbers and the depth of sapwood. In this figure the average diameter is considered and the effect of differences in taper is neglected.

If the average penetration is shallow, as may be the case in light treatments or where the sapwood is thin or particularly resistant, the ratio of surface area to volume is a satisfactory measure of the relative absorptions required to obtain equivalent treatments in timbers

of different diameters. By the term equivalent treatment is meant one that will give an absorption that is either proportional to the amount of sapwood or to the surface area per unit volume. When the sapwood is deep the ratio of the percentage of sapwood in the total volume is a better measure of the proportional absorptions required.

Assuming, for convenience, that the round timbers are cylindrical in shape, then $R=\frac{4}{D}$ where R is the ratio of circumferential area to volume and D is the average diameter of the timber. When D is in inches R is the number of square inches per cubic inch, and when D is in feet R is the number of square feet per cubic foot.

If t is the average depth of sapwood and D is the average diameter then the percentage of sapwood based on the total volume is

$$100\left[\frac{4t\ (D-t)}{D^2}\right]$$

Let it be assumed that a timber of diameter D has an absorption of P pounds per cubic foot and it is desired to obtain a proportional or equivalent treatment in a timber having a diameter d. Based on the ratio of surface area, the absorptions of the timber having a diameter d should be

$$P\left[\frac{4}{d}\div\frac{4}{D}\right]=P\left(\frac{D}{d}\right)$$

On the other hand, if the absorption is based on the relative proportions of sapwood, the required absorption in the timber of diameter d is evidently

$$P\left[\frac{4t_1(d-t_1)}{d^2}\div\frac{4t_2(D-t_2)}{D^2}\right]$$

If in the preceding expression t_1, the sapwood depth in the timber of diameter d, is the same as t_2, the sapwood depth in the timber of diameter D, then the required absorption in the timber of diameter d is

$$P\left[\frac{(d-t)D^2}{(D-t)d^2}\right]$$

It may be noted that if $t=O$ in this expression, the latter becomes $P\left[\frac{D}{d}\right]$ which is the absorption based on the ratio of surface areas. In other words, as the depth of sapwood decreases the required absorption approaches as a limit that indicated by the ratio of surface areas.

EXAMPLE OF THE COMPUTATION OF PROPORTIONAL ABSORPTIONS IN ROUND TIMBERS

One group of poles has an average diameter D of 12 inches and another group has an average diameter d of 8 inches. The average absorption P specified for the 12-inch diameter poles is 8 pounds per cubic foot and the average sapwood thickness t is 1 inch. What absorption should be specified for the 8-inch diameter poles (with the same sapwood thickness) in order to obtain a treatment equivalent or proportional to that specified for the poles of larger diameter?

Based on the ratio of surface area, the absorption in the 8-inch diameter poles should be $8\left(\frac{12}{8}\right)$ or 12 pounds per cubic foot. This will give the same absorption in pounds for each square foot of circumferential surface area. If the ratio of proportional amounts of sapwood is taken as the basis, the absorption in the smaller diameter timber is

$$8\left(\frac{(8-1)\ 144}{(12-1)\ 64}\right)$$

or 11.45 pounds per cubic foot. The absorption in this case will be the same in pounds per cubic foot of sapwood for each timber. This is approximately 5 percent less than that based on surface area. If the average depth of sapwood were 3 inches instead of 1 inch, the required absorption in the 8-inch diameter timber, based on proportion of sapwood, is

$$8\left(\frac{(8-3)\ 144}{(12-3)\ 64}\right)$$

or 10 pounds per cubic foot. This is nearly 17 percent less than when the absorption is based on the ratio of surface area.

Figure 33 can be used conveniently for finding the percentage of sapwood directly and the ratio of sapwood in timbers of different diameter is readily determined from these values. From this figure the sapwood in the 12-inch diameter poles is found to be 75 percent of the total volume for a thickness of 3 inches while that in the 8-inch diameter is found to be about 94 percent for the same depth of sapwood. The necessary absorption for the 8-inch pole is found to be (94÷75) or about 1.25 times that required in the larger size as shown in the preceding example.

Figure 33 is also useful in estimating the maximum amount of preservative that poles or piling having different average depths of sapwood will absorb, since in general only the sapwood is treated. The approximate percentage of air space P can be found from figure 8 for the species treated. If S_p is the percentage sapwood found from figure 33 and W is the weight in pounds per cubic foot of the preservative at the treating temperature, the maximum amount of preservative that could be absorbed, assuming all the available air space filled, is

$$\frac{P}{100}\times\frac{S_p}{100}\times W \text{ pounds per cubic foot}$$

The maximum absorption will necessarily be somewhat less than this because all the air space in the treated sapwood cannot be completely filled regardless of the method of treatment used.

Table 16 shows the surface area and volume per foot length of different sizes of sawed and round timbers. The areas given in this table are actual surface areas for timbers of the dimensions given and do not take into account relations of end to side penetration. In the table the nominal sizes are used; that is, in computations of volume and surface area for the sawed timbers account is not taken of the fact that the actual dimensions of lumber and timber are usually somewhat less than the nominal dimensions. For simplicity the round timbers were assumed as cylindrical in shape, which is sufficiently close for practical purposes since the average diameter can be used.

TABLE 16.—*Surface area*[1] *and volume per foot length of different sizes of timber*

[Nominal dimensions]

SAWED MATERIAL

Nominal size of timber (inches)	Total side surface area per foot length	Total end surface area (both ends)	Volume per foot length
Lumber and dimension sizes:	*Square feet*	*Square foot*	*Cubic foot*
2 by 4	1.000	0.111	0.056
2 by 6	1.333	.167	.083
2 by 8	1.667	.222	.111
2 by 10	2.000	.278	.139
2 by 12	2.333	.333	.167
3 by 4	1.167	.167	.083
3 by 6	1.500	.250	.125
3 by 8	1.833	.333	.167
3 by 10	2.167	.417	.208
3 by 12	2.500	.500	.250
4 by 4	1.333	.222	.111
4 by 6	1.667	.333	.167
4 by 8	2.000	.444	.222
4 by 10	2.333	.556	.278
4 by 12	2.667	.667	.333
Boards and strips:			
1 by 2	.500	.028	.014
1 by 3	.667	.042	.021
1 by 4	.833	.056	.028
1 by 5	1.000	.069	.035
1 by 6	1.167	.083	.042
1 by 8	1.500	.111	.056
1 by 10	1.833	.139	.069
1 by 12	2.167	.167	.083
Tie sizes commonly used:			
6 by 6	2.000	.500	.250
6 by 7	2.167	.583	.292

Nominal size of timber (inches)	Total side surface area, per foot length	Total end surface area (both ends)	Volume per foot length
Tie sizes commonly used—Con.	*Square feet*	*Square feet*	*Cubic feet*
6 by 8	2.333	0.667	0.333
7 by 7	2.333	.681	.340
7 by 8	2.500	.778	.389
7 by 9	2.667	.875	.438
7 by 10	2.833	.972	.486
Timber sizes:			
6 by 6	2.000	.500	.250
6 by 8	2.333	.667	.333
6 by 10	2.667	.833	.417
6 by 12	3.000	1.000	.500
6 by 14	3.333	1.167	.583
6 by 16	3.666	1.333	.667
8 by 8	2.667	.889	.444
8 by 10	3.000	1.111	.556
8 by 12	3.333	1.333	.667
8 by 14	3.667	1.556	.778
8 by 16	4.000	1.778	.889
10 by 10	3.333	1.389	.694
10 by 12	3.667	1.667	.833
10 by 14	4.000	1.944	.972
10 by 16	4.333	2.222	1.111
12 by 12	4.000	2.000	1.000
12 by 14	4.333	2.333	1.167
12 by 16	4.667	2.667	1.333
14 by 14	4.667	2.722	1.361
14 by 16	5.000	3.111	1.555
16 by 16	5.333	3.555	1.778

ROUND TIMBERS

Mean diameter (inches)	Total side surface area, per foot length	Total end surface area (both ends)	Volume per foot length
	Square feet	*Square feet*	*Cubic feet*
4	1.047	0.175	0.087
5	1.309	.273	.136
6	1.571	.393	.196
7	1.833	.535	.267
8	2.094	.698	.349
9	2.356	.884	.442
10	2.618	1.091	.545
11	2.880	1.320	.660
12	3.142	1.571	.785
13	3.403	1.844	.922
14	3.665	2.138	1.069
15	3.927	2.454	1.227
16	4.189	2.792	1.396
17	4.451	3.152	1.576

Mean diameter (inches)	Total side surface area, per foot length	Total end surface area (both ends)	Volume per foot length
	Square feet	*Square feet*	*Cubic feet*
18	4.712	3.534	1.768
19	4.974	3.938	1.969
20	5.236	4.363	2.182
21	5.498	4.811	2.405
22	5.760	5.280	2.640
23	6.021	5.771	2.885
24	6.283	6.283	3.142
25	6.545	6.818	3.409
26	6.807	7.374	3.687
27	7.069	7.952	3.976
28	7.330	8.552	4.276
29	7.592	9.174	4.587
30	7.854	9.818	4.909

[1] The areas given are the actual areas for timbers of the dimensions given and do not take into consideration relations of end to side penetration.

MEASUREMENT OF ABSORPTION

In making preservative treatments the absorptions are usually determined by one of the following methods: (1) By taking gage readings and determining the difference in the volume of preservative contained in the working tank before and after treatment; (2) by using a working tank mounted on scales and weighing the total amount of preservative absorbed, or (3) by taking weights of the charge of timber before and after it is treated. The volumetric measurement of the amount of preservative absorbed, reduced to

pounds per cubic foot, is the oldest method and is still the one most commonly used.

Advantages in favor of the weighing-tank method as compared with tank-gage readings are that more accurate determinations of the absorption can be made because it reduces the possibility of errors which may be introduced by such factors as the expansion of preservative, cylinder, and measuring tanks due to change in temperature, friction affecting the movement of the gage, and difficulty of making accurate readings of small changes in the height of the liquid in the measuring or working tank. Weighing the wood on track scales before and after treatment affords a very dependable method of measuring absorption in air-seasoned material but it has a disadvantage when the charge is given a preliminary steaming treatment because the moisture content and hence the weight of the wood is changed by the steaming. The weight of the timber cannot be conveniently determined after completing the vacuum following steaming and before the preservative is admitted to the cylinder. The same objection applies when the material is conditioned by the Boulton method unless the amount of water withdrawn from the wood during the vacuum period is measured accurately. The amount of water condensed during the Boulton treatment is not a true measure of the amount of moisture removed from the wood unless the oil is free from water when it is admitted to the cylinder and all of the vapors withdrawn by the vacuum pump are condensed.

Unless proper care is exercised absorption measurements made by taking gage readings or by weighing the working tank may be subject to considerable error. Small leaks in valves may allow a large amount of preservative to pass out of the cylinder during the pressure period and unless this preservative is returned to the working tank before treatment is completed a false reading of absorption will be obtained.

Specifications of the American Wood Preservers' Association [9] require that all tank volume readings be reduced to that of the preservative at 100° F. Table 17 shows the factors to be used for computing the volume of creosote oil at 100°.

Table 17.—*Factors to be used for determining the volume of creosote oil at 100° F. when the oil is at temperatures ranging from 60° to 220° F.*[1]

[Group 1, for distillate creosote including distillate water-gas-tar creosote, having a specific gravity at 100°/60° F. below 1.0900. Group 2, for high boiling distillate creosote oils having a specific gravity at 100°/60° above 1.0900]

Observed temperature (° F.)	Volume [2] at 100° F. occupied by unit volume at indicated temperature		Observed temperature (° F.)	Volume [2] at 100° F. occupied by unit volume at indicated temperature		Observed temperature (° F.)	Volume [2] at 100° F. occupied by unit volume at indicated temperature	
	Group 1	Group 2		Group 1	Group 2		Group 1	Group 2
220	0.9526	0.9570	211	0.9561	0.9601	202	0.9597	0.9633
219	.9530	.9573	210	.9565	.9605	201	.9601	.9636
218	.9534	.9577	209	.9569	.9608	200	.9605	.9640
217	.9538	.9580	208	.9573	.9612	199	.9609	.9644
216	.9542	.9584	207	.9577	.9615	198	.9612	.9647
215	.9546	.9587	206	.9581	.9619	197	.9616	.9650
214	.9550	.9591	205	.9585	.9622	196	.9620	.9654
213	.9554	.9594	204	.9589	.9626	195	.9624	.9658
212	.9558	.9598	203	.9593	.9629	194	.9628	.9661

[1] Data determined by Bureau of Standards, U. S. Department of Commerce.
[2] The observed volume is to be multiplied by the factor corresponding to the observed temperature.

[9] American Wood Preservers' Association manual of recommended practice, 33b. Standard instructions for the inspection of preservative treatment of wood. (Loose leaf.)

TABLE 17.—*Factors to be used for determining the volume of creosote oil at 100° F. when the oil is at temperatures ranging from 60° to 220° F.*—Continued

Observed temperature (° F.)	Volume at 100° F. occupied by unit volume at indicated temperature		Observed temperature (° F.)	Volume at 100° F. occupied by unit volume at indicated temperature		Observed temperature (° F.)	Volume at 100° F. occupied by unit volume at indicated temperature	
	Group 1	Group 2		Group 1	Group 2		Group 1	Group 2
193	0.9632	0.9665	161	0.9758	0.9779	130	0.9881	0.9891
192	.9636	.9668	160	.9762	.9782	129	.9885	.9894
191	.9640	.9672	159	.9766	.9786	128	.9889	.9898
190	.9644	.9675						
189	.9648	.9679	158	.9770	.9790	127	.9893	.9902
188	.9652	.9682	157	.9774	.9793	126	.9897	.9905
187	.9656	.9686	156	.9778	.9797	125	.9901	.9909
186	.9660	.9689	155	.9782	.9800	124	.9905	.9913
185	.9664	.9693	154	.9786	.9804	123	.9909	.9916
184	.9668	.9696	153	.9790	.9808	122	.9913	.9920
183	.9672	.9700	152	.9794	.9811	121	.9917	.9923
182	.9676	.9704	151	.9798	.9815	120	.9921	.9927
181	.9680	.9707	150	.9802	.9819	119	.9925	.9931
180	.9684	.9711	149	.9806	.9822	118	.9929	.9934
179	.9687	.9714	148	.9810	.9826	117	.9932	.9938
178	.9691	.9718	147	.9814	.9830	116	.9936	.9942
177	.9695	.9721	146	.9818	.9833	115	.9940	.9945
176	.9699	.9725	145	.9822	.9837	114	.9944	.9949
175	.9703	.9729	144	.9826	.9840	113	.9948	.9952
174	.9707	.9732	143	.9830	.9844	112	.9952	.9956
173	.9711	.9736	142	.9834	.9848	111	.9956	.9960
172	.9715	.9739	141	.9838	.9851	110	.9960	.9963
171	.9719	.9743	140	.9842	.9855	109	.9964	.9967
170	.9723	.9746	139	.9846	.9858	108	.9968	.9971
169	.9727	.9750	138	.9850	.9862	107	.9972	.9974
168	.9731	.9754	137	.9853	.9866	106	.9976	.9978
167	.9735	.9757	136	.9857	.9869	105	.9980	.9982
166	.9739	.9761	135	.9861	.9873	104	.9984	.9985
165	.9743	.9764	134	.9865	.9876	103	.9988	.9989
164	.9747	.9768	133	.9869	.9880	102	.9992	.9992
163	.9751	.9772	132	.9873	.9884	101	.9996	.9996
162	.9754	.9775	131	.9877	.9887	100	1.0000	1.0000
FOR USE ONLY WHEN THE SAMPLE OF OIL HAS BEEN EXAMINED AND FOUND FREE FROM CRYSTALS								
99	1.0004	1.0004	85	1.0059	1.0054	72	1.0111	1.0100
98	1.0008	1.0007	84	1.0063	1.0057	71	1.0115	1.0104
97	1.0012	1.0011	83	1.0067	1.0061	70	1.0118	1.0108
96	1.0016	1.0014						
95	1.0020	1.0018	82	1.0071	1.0065	69	1.0122	1.0111
94	1.0024	1.0022	81	1.0075	1.0068	68	1.0126	1.0115
93	1.0028	1.0025	80	1.0079	1.0072	67	1.0130	1.0118
92	1.0032	1.0029	79	1.0083	1.0075	66	1.0134	1.0122
91	1.0036	1.0032	78	1.0087	1.0079	65	1.0138	1.0126
90	1.0040	1.0036	77	1.0091	1.0083	64	1.0142	1.0129
89	1.0043	1.0040	76	1.0095	1.0086	63	1.0146	1.0133
88	1.0047	1.0043	75	1.0099	1.0090	62	1.0150	1.0136
87	1.0051	1.0047	74	1.0103	1.0093	61	1.0154	1.0140
86	1.0055	1.0050	73	1.0107	1.0097	60	1.0158	1.0144

Figure 34 will be found convenient for determining the volumetric absorption, in percentage of the total volume of the charge, for a given specified absorption in pounds or in gallons per cubic foot. The range of specific gravities shown is from 0.92 to 1.12 for differences of 0.04 in each interval. Intermediate values can be easily determined by interpolating. The readings are net absorptions. Since there is always a kick-back after treatment the gross absorption should be proportionately increased. The specific gravity for a given preservative temperature is found by multiplying the volume-correction factor found from table 17 by the specific gravity at the temperature at which it was determined. For example, the specific gravity at 100° F. is 1.06; what is the specific gravity at 200° F.? From table 17 the correction factor is found to be 0.9605. The specific gravity at 200° is then $(0.9605)\times(1.06)=1.018$.

EXAMPLE OF THE USE OF FIGURE 34

An absorption of 15 pounds per cubic foot is specified and the specific gravity of the preservative at the temperature used is 1.04. What is the required net absorption in percentage of total volume of charge and in gallons per cubic foot?

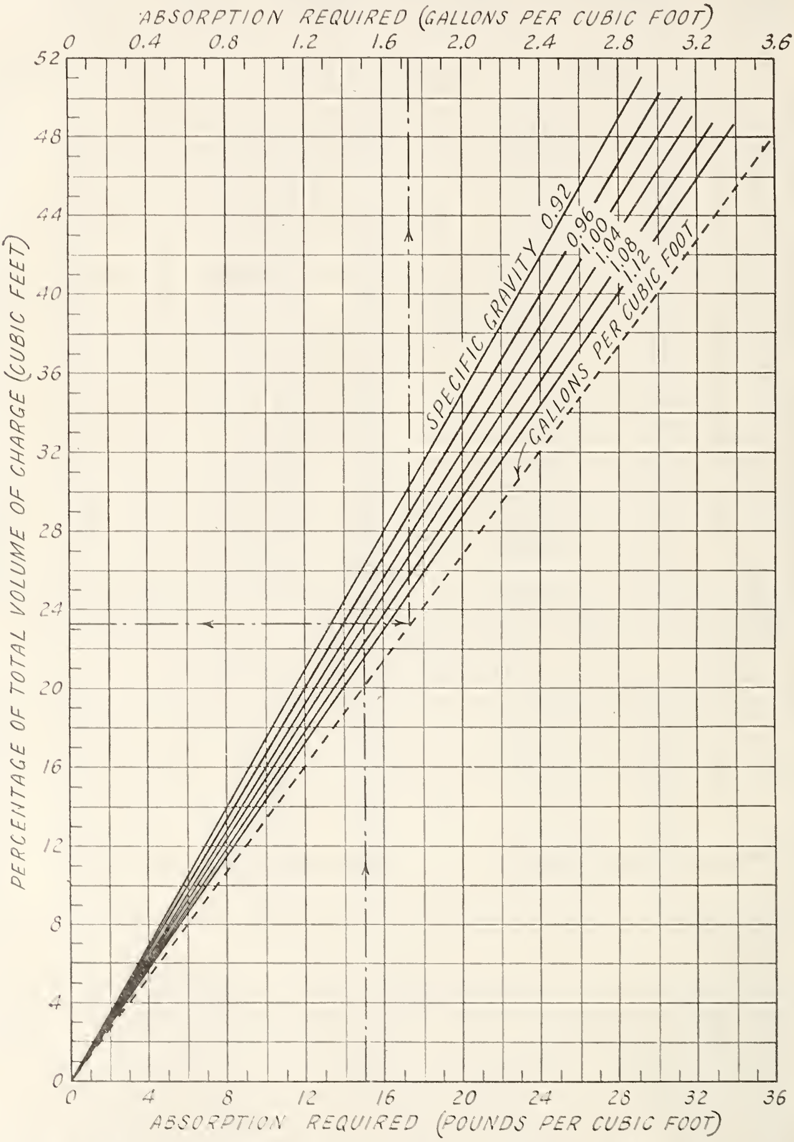

FIGURE 34.—Percentage of volumetric absorption required for preservatives at different specific gravities to obtain a given absorption in pounds or gallons per cubic foot. (Dotted line is for absorptions in gallons per cubic foot. Scale for absorptions in pounds per cubic foot is at bottom of figure and scale for absorption in gallons per cubic foot is shown at top.)

Starting in figure 34 on the horizontal scale with the specified absorption of 15 pounds per cubic foot, follow vertically until an intersection is made with the diagonal line labeled specific gravity 1.04. The reading on the left vertical scale corresponding to the intersection point is found to be about 23.2 percent, which

indicates that for each cubic foot of wood in the charge 0.232 cubic foot of preservative should be injected; projecting horizontally across to the diagonal dotted line labeled gallons per cubic foot and then directly above to the horizontal scale, it is found that the required absorption is about 1.73 gallons per cubic foot. The lines with arrows (fig. 34) show the procedure for this example. If in this case it is found from experience that a gross absorption of 18 pounds is necessary to obtain the net retention of 15 pounds, the chart shows that this absorption (18 pounds) requires about 28 percent, or 0.28 cubic foot of preservative per cubic foot of wood. Expressed in gallons, the gross absorption is found to be about 2.1 gallons per cubic foot of wood.

It may be noted that when absorptions are specified in pounds per cubic foot of wood a greater volumetric absorption of the preservative will be obtained with a preservative having a low specific gravity than with one having a high specific gravity since the absorptions by volume are inversely proportional to the specific gravities.

Assume for illustration that a creosote-petroleum mixture has a specific gravity of 0.94 at the treating temperature and a creosote-tar solution has a specific gravity of 1.08 at the same temperature. For a given absorption in pounds per cubic foot the ratio of the volumetric absorption of the creosote-tar solution to that of the creosote-petroleum mixture will be (0.94÷1.08) or about 87 percent. In other words, the unit volumetric absorption of the preservative oil with the higher specific gravity will be about 13 percent less than that of the oil with the lower specific gravity.

Differences in the specific gravity of oils used in preservative mixtures made by volume will affect the proportion of each absorbed by weight. For example, assume a petroleum oil having a specific gravity of 0.9 at the treating temperature is mixed with an equal volume of creosote having a specific gravity of 1.02 at the same temperature. If P is the specified absorption in pounds per cubic foot then the weight of petroleum injected per cubic foot will be

$$P\left(\frac{0.9}{0.9+1.02}\right)=0.469P$$

The weight of creosote will be

$$P\left(\frac{1.02}{0.9+1.02}\right)=0.531P$$

An 8-pound treatment of the 50–50 mixture would then contain 3.75 pounds of petroleum and 4.25 pounds of creosote per cubic foot.

If the mixture contained 45 percent of petroleum and 55 percent of creosote, the weight of petroleum per pound absorption of the mixture would be

$$\left[\frac{(0.9)(0.45)}{(0.9)(0.45)+(1.02)(0.55)}\right]=0.42 \text{ pound}$$

and the weight of creosote (1—0.42) or 0.58 pound. With a mixture of this proportion the 8-pound treatment would therefore give an absorption of 3.36 pounds of petroleum and 4.64 pounds of creosote per cubic foot. In the first case the absorption of creosote is more than 13 percent greater by weight than the absorption of petroleum, while in the second case, when the difference in volumetric proportions is 10 percent, the absorption of creosote is over 38 percent greater by weight than that of the petroleum.

During the filling of the cylinder with the preservative, when air-seasoned or steamed material is treated and also during the boiling-under-vacuum period when the Boulton process is employed, there is more or less absorption of preservative, known as initial absorption. The amount of this initial absorption will vary, depending on the treating conditions and similar factors.

Air-seasoned hemlock ties when treated by the full-cell process with preservative oils and water solutions had an initial absorption ranging from about 1.5 to 3 pounds and averaged about 2 pounds per cubic foot. The initial absorption in several charges of seasoned red-oak ties impregnated by the full-cell process with water solutions and preservative oils ranged from about 3.5 to 6 pounds per cubic foot and averaged about 4 pounds. The allowance that should be made for the initial absorption and kick-back can usually be estimated fairly closely after a few charges of timber have been treated.

EFFECT OF TREATMENT ON THE PHYSICAL CONDITION OF THE WOOD

As previously discussed on pages 48 and 58 improper steaming or boiling conditions may injure the strength of the wood. In addition, improperly controlled treating conditions may cause severe checking or collapse of the wood. It is not established that these effects necessarily indicate reduction in strength. There may be appreciable reduction in strength without visible signs of injury, and it seems quite possible that there may be collapse and considerable checking without much loss in strength. This visible damage often accompanies loss in strength, however, and in any event it is undesirable.

Since the different species and even timbers of the same species vary widely in the degree to which they are affected by any given treatment, it is not possible to recommend any fixed treating condition or to state definite limits for all of the treating variables. In every treatment, however, an effort should be made to use as mild conditions as are practicable.

The sapwood of most species is much less subject to visible injury—such as checking and collapse—than the heartwood, and for this reason sawed sapwood material or round timbers that are largely sapwood can be treated without visible injury under higher pressures and temperatures than sawed timbers that have exposed heartwood faces. Round timbers with thin sapwood and species that have fairly resistant sapwood are often similar to heartwood material in susceptibility to visible injury. In general, the denser woods, such as many of the hardwoods, show less tendency to checking and collapse under high pressures than the lower density woods. Timbers of about the same density but of different species may, however, show a considerable disparity in resistance to checking and collapse.

Experiments have also shown that the size of the timber and whether water solutions or oils are used have a bearing on the results obtained. In strength tests it was found that the strength properties of timbers of large dimension were more easily injured by high temperatures and long-continued heating than those of timbers of smaller sizes. On the other hand, both air-seasoned and steamed timbers with small cross-sectional dimensions were apparently more easily collapsed during the preservative treatment. Timbers treated

with water solutions showed a greater tendency to collapse than the same kind of material impregnated with preservative oils under the same treating conditions. This is probably because the water solutions soften the wood more than do preservative oils. Figure 35 shows cross sections from the centers of 4- by 4- by 48-inch heartwood specimens treated with a water solution under pressures of 150 and 175 pounds. The shaded portion indicates the original size of each specimen. The two specimens were the most severely collapsed of those treated but the results showed that the pressures used were too high for the species and size of specimens. Nearly all of the pieces treated under these pressures were more or less severely injured, while little or no collapse occurred in specimens treated under the same conditions but with pressures of 100 and 125 pounds. While these specimens were collapsed by the treating conditions used, less easily injured woods might show no indication of collapse under the same treatment. As previously mentioned, it is important to keep the

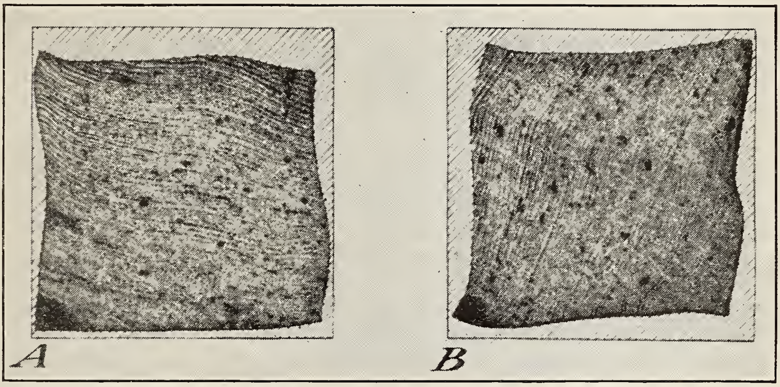

FIGURE 35.—Collapse in 4- by 4- by 48-inch specimens treated with a water solution: *A*, At 150 pounds pressure; *B*, at 175 pounds.

preservative pressure sufficiently low in order to avoid collapse and checking under the temperature conditions necessary for satisfactory treatment.

BLEEDING OF TREATED WOOD

In wood treated with creosote or creosote mixtures the oil may sometimes "bleed" or ooze to the surface after the wood is in use and thus cause inconvenience under certain conditions of service. The phenomenon is not encountered with water solutions except perhaps for a very brief time immediately after removal from the treating cylinder, for in a short time the water evaporates, leaving no free liquid that can bleed from the wood. Bleeding may occur, however, with any oil sufficiently liquid to flow at atmospheric temperatures. This trouble is sometimes of concern in poles, crossarms, or timbers used in places where the dripping preservative or the oily surface may cause damage or public complaint but it is seldom of importance in crossties or piling.

The causes of bleeding are not well understood but it is apparently influenced chiefly by the intensity of exposure to sunshine or other source of heat. The dark color of the treated wood causes it to absorb

considerable heat from the sun. Temperatures as high as 140° F. have been measured at the surface of a creosoted timber in direct sunshine. It is quite possible that higher temperatures may be reached under favorable conditions. The bleeding may occur either in summer or winter but is usually greatest in the summer. Although this oozing of the preservative is usually at its worst during the first year after treatment, it may occur to a certain extent on some poles over a period of several years. In a pole or other timber the bleeding will usually be confined to the surface facing the sun. Apparently it is a direct result of the heating and expansion of air and oil in the affected portion and the inability of the expanded oil to flow in any direction except toward the surface. Bleeding, of course, would not occur if the preservative could not flow at the temperatures reached by the wood in the sunshine.

The character of the preservative used has an important influence upon bleeding. Straight coal-tar creosote is less likely to cause trouble than mixtures of creosote with tar or petroleum. Perhaps the mixtures do not bleed more but they remain on the surface longer and are more troublesome than straight creosote. Similarly, low-boiling creosotes are less troublesome than high-boiling creosotes or those that show a high residue above 355° C. One proprietary process that has met some degree of success in preventing bleeding combines a high melting wax with the creosote, producing a mixture that does not flow at the temperatures ordinarily reached by the wood. A more recent process also makes use of a wax but not in sufficient percentage to cause congealing of the preservative at moderate atmospheric temperatures.

The quantity of preservative injected affects bleeding. Very high absorptions are more likely to bleed than lower absorptions injected by the same method. Differences in method of injection, however, must also be considered. In experiments with paving blocks (*30*) it was found that the amount of air in the wood had a very marked effect on bleeding. Blocks treated by the Rueping process bled much more than those treated by the full-cell process. Blocks treated by the full-cell process after preliminary steaming and vacuum bled least. The air used in empty-cell treatments of heartwood timbers does not all escape with the completion of the treating process. The expansion of the air that remains in the wood apparently adds to the effect of the expansion of the oil on exposure of the treated wood to strong sunshine. This is not such an important factor in the more easily treated sapwood since the resistance to the movement of air through the sapwood is much less than in the heartwood.

Heartwood and resistant woods in general appear more subject to bleeding than sapwood but it is true that sapwood may also bleed copiously. On sawed surfaces, however, where both heartwood and sapwood are exposed the heartwood seems to have the greater tendency to bleed.

It must not be assumed from the above statements that all creosoted wood gives trouble from bleeding. Many pole lines and structures of various kinds have been built of creosoted wood that have given no trouble whatever from bleeding. The difficulty is not that the wood always bleeds but that the treating-plant operator is unable to guarantee that his treated material will be entirely free from bleeding.

The following methods are used to help reduce bleeding. In one, called the expansion bath, the pressure is released at the end of the pressure period and then, with the charge of timber still submerged, the temperature of the oil is raised from 10° to 20° F. above the temperature maintained during the pressure period. A vacuum is sometimes applied during this heating period to assist further in removing the air and excess preservative. Specifications for the use of the expansion bath with Douglas fir timbers usually limit the total time of the expansion bath to a maximum of 2 hours. After the expansion bath the preservative is withdrawn from the cylinder and a final vacuum is applied in the usual manner.

At some plants a final steam bath is used. After the completion of the pressure period and the withdrawal of the oil, steam is admitted until a pressure of 15 to 20 pounds is reached and this is held for 15 minutes or longer, depending on the judgment of the plant operator. A final vacuum is applied after the steam treatment. This final steaming treatment, like the expansion bath, is intended to reduce the amount of air in the wood cells and remove some of the free oil near the surface. It also helps to clean off the surface of the wood. A third method employed by a few plants is the use of a final air pressure after the preservative has been withdrawn from the cylinder. Air at pressures up to as high as 150 pounds or more is applied for a period of 3 to 4 hours for the purpose of forcing the free oil further into the wood.

A considerable amount of observation and study will be necessary to determine the relative importance of the factors that encourage bleeding and to find the most effective means of preventing it.

TREATING CONDITIONS USED IN COMMERCIAL PRACTICE

Tables 18 to 20, inclusive, summarize the commercial treating methods employed for various species and different kinds of material. These tables include data obtained from a large number of the wood-preserving plants operating in the United States as well as from some of those in Canada, and show representative treating practice for different regions. These data were obtained between 1928 and 1933. The diversity in conditions used for treating the same or similar material reflects some of the lack of information and difference of opinion as to conditions that are considered most satisfactory.

122138°—35——7

TABLE 18.—*Commercial treating conditions and absorptions in use for Douglas fir (coast type)*

Plants studied (number)	Preliminary air pressure [2]	Preservative used: Coal-tar creosote	Preservative used: Petroleum	Maximum treating pressure	Preservative temperature	Final hot bath in preservative		Final vacuum	Net absorption	Remarks
	Pounds per square inch	*Percent*	*Percent*	*Pounds per square inch*	*° F.*	*Hours*	*° F.*	*Hours*	*Pounds per cubic foot*	
GREEN TIES (conditioned by Boulton process)[1]										
1	70	100		140–150	190–200	1	190	2–3	7– 8	
1	100	50	50	170	190–200			3	7	
1	75	50	50	150	175–180	2½	170–210	1–2	7½	
AIR-SEASONED TIES [3]										
1		50	50	120	180–200				7– 8	Lowry process. Final air pressure at 70 pounds for 4 hours.
1		45	55	160	170–180			½	8	Lowry process. Boiled under vacuum at 170° F. for about 3 hours.
2	65	70	30	175	185–200	2½	225	2	5½– 7½	
2	55–60	70	30	175	175–180			1½	7½– 8	Boiled under vacuum for 2 to 3 hours at 175° to 180° F.
1	100	45	55	175	180			1½	8	
1	20	100		125	180–185			1	6– 8	
1		40	60	175	180			1	7– 8	Lowry process.
1		50	50	175	180–190			1½–2	8	Preliminary hot bath in oil at 180° to 200° F. for 5 hours.
1	50–125	50	50	175	180–185			1½	7	
1		50	50	150–175	180–200			1	7	Lowry process. Final air pressure of 175 pounds for 3 to 4 hours.
GREEN LUMBER AND BRIDGE TIMBERS (conditioned by Boulton process)[4]										
2	70	100		160–175	160–170 190–200	1–1½	190	2–4	6– 8	
1		100		60–70	190–200				6–14	Full-cell treatment. Final air pressure at 60–70 pounds for 4 to 5 hours.
1	70	100		130	175	2½	220	2	6	
1		100		135	170			1	8– 9	Full-cell treatment.

AIR-SEASONED LUMBER AND BRIDGE TIMBERS[5]

1		100		100	180			1–1½	12	Timber first heated in creosote at 180° F. for 3 to 5 hours before pressure is applied.
1	30	100		150–175	180–200			1–1½	6	

GREEN PILING (conditioned by Boulton process)[6]

2		100		130–150	190–210			½–3	12	Full-cell treatment. Partially air-seasoned material boiled under vacuum 25 to 30 hours.
1		100		60–70	200				6–16	Full-cell treatment. Final air pressure at 60 to 70 pounds for 4 to 5 hours.
1		100		100	175–180			2	8–12	Full-cell treatment.
1		100		100–125	160–190	1	230	1½–2	12	Do.
1		100		150	190			1½	12	Do.
1	30	100		130	185–190			1½	8	

AIR-SEASONED OR PARTIALLY AIR-SEASONED PILING[7]

1		100		150	185–190			1	12–14	Full-cell treatment. Boiled under vacuum for about 24 hours.
1		100		100	180			1½	10	Piling is first heated in creosote at 180° F. for 3 to 5 hours before pressure is applied.

GREEN POLES (conditioned by Boulton process)[8]

1		100		60–70	190–200	2	220	3	8	Lowry process.
2	15–20	100		100–125	160–200	1	220	¼–2	8	Steamed at atmospheric to 15 pounds pressure before final vacuum.

[1] Pressure periods maintained ¾ to 3½ hours.
[2] Air pressure held for ½ to 1½ hours before admitting preservative
[3] Pressure periods maintained 1 to 9 hours.
[4] Pressure periods maintained 1 to 2½ hours.
[5] Pressure periods maintained 3 to 15 hours.
[6] Pressure periods maintained ½ to 10 hours.
[7] Pressure periods maintained 1½ to 15 hours.
[8] Pressure periods maintained ½ to 2 hours.

TABLE 19.—*Commercial treating conditions and absorptions in use for air-seasoned material of species grown in the Central and Rocky Mountain States*

TIES

Plants studied (number)	Species treated	Preservative: Coal-tar creosote	Preservative: Petroleum	Preservative: Coal tar	Preservative: Zinc chloride solution	Preliminary air pressure [1]	Treating pressure [2]	Preservative temperature	Final vacuum [3]	Net absorption of oil or dry salt
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Pounds per square inch*	*Pounds per square inch*	°*F.*	*Hours*	*Pounds per cubic foot*
1	Beech	100					200–210	175–180	½	8–9
1	do	100				60–65	200–210	175–180	½	6
1	do				100		200–210	175–180	½	½
1	do	50	50			(4)	125–140	170–185	1½	8
1	Birch, yellow	100					200–210	175–180	½	8–9
1	do	100				60–65	200–210	175–180	½	6
1	do				100		200–210	175–180	½	½
1	do	50	50			(4)	125–140	170–185	1½	8
1	Douglas fir (Rocky Mountain type).	50	50			(4)	[5] 150–175	180–200	1	4–7
1	do	50	50				[6] 150–175	180–190	1½–2	4–8
1	do	40	60			(4)	175–200	180	1	5–8
1	do				100		175–200	180	½	½
1	do	50	50			(4)	170	160	½	7
1	do				100		190	160–170	¾	½
1	do	70	30				[7] 135	160–200	1½	5–6
1	do	45	55			40	135	165–185	1½	3–7
1	do	55	45			(4)	225	180	1½	3–5
2	Gum	80		20		50–60	150–200	185–210	1 –1½	6
1	do	70	30			40	135	160–200	1½–2	6–8
1	Hemlock, eastern	100					200–210	175–180	½	8–9
1	do	100				60–65	200–210	175–180	½	6
1	do				100		200–210	175–180	½	½
1	Hemlock, western	70	30			65	175	190–200	1½	5½
1	do	50	50				[6] 150–175	180–190	1½–2	4–8
1	do				100		150	170–200		½
1	Larch, western	50	50				[6] 150–175	180–190	1½–2	4–8
1	do	40	60			(4)	175–200	180	1	5–8
1	do				100		175–200	180	½	½
1	do	50	50			(4)	170	160	½	7
1	do				100		190	160–170	¾	½
1	Maple	100					200–210	175–180	½	8–9
1	do	100				60–65	200–210	175–180	½	6
1	do				100		200–210	175–180	½	½
1	do	50	50			(4)	125–140	170–185	1½	8
1	Oak, red	100					200–210	175–180	½	8–9
1	do	100				60–65	200–210	175–180	½	6
1	do				100		200–210	175–180	½	½
2	do	80		20		50–60	150–200	185–210	1 –1½	6
1	do	80		20		50–60	175–180	175–180	1 –1½	6
1	do	70	30			40	135	160–200	1½–2	6–8
1	do	80		20		50–60	175	190–200	1½	4–6
1	do				100		105–160	180	⅓– ½	½
1	Oak, white	80		20		50–60	175	190–200	1½	4–6
1	do				100		150–160	180	⅓– ½	½
1	Pine, lodgepole				100		175	180	½	½
1	do	70	30			65	175	190–200	1½	5½
1	do				100		175	180–190	½	½
1	do	50	50			50–125	175	180–185	1½	7
1	do	50	50			(4)	[5] 150–175	180–200	1	4–7
1	do	50	50				[6] 150–175	180–190	1½–2	4–8
1	do				100		150	170–200		½
1	Pine, ponderosa				100		175	180	½	½
1	do	50	50			(4)	[5] 150–175	180–200	1	4–7
1	do	50	50				[6] 150–175	180–190	1½–2	4–8
1	do	70	30			60	135	160–200	1½	7–8
1	do	45	55			65	175	165–185	2	7½
1	do	55	45			80–90	150–175	180	1½	7

[1] Air pressure held for about 30 minutes before admitting preservative.
[2] Pressure periods for the oaks, beech, birch, and maple, 2 to 5 hours; eastern hemlock, 6 to 8 hours; lodgepole pine, western larch, Douglas fir (mountain type), 3 to 9 hours; ponderosa pine and southern yellow pine, 1 to 4 hours; western hemlock, 2½ to 5 hours.
[3] With full-cell process preliminary vacuum period varied from ¼ to 1 hour.
[4] Lowry process.
[5] Final air pressure of 175 pounds applied for 3 to 4 hours.
[6] Refractory species are heated in preservative at 180° to 200° F. for 5 hours before pressure is applied.
[7] Heated in preservative at 180° F. for 4 hours before pressure is applied.

TABLE 19.—*Commercial treating conditions and absorptions in use for air-seasoned material of species grown in the Central and Rocky Mountain States*—Cont'd.

TIES—Continued

Plants studied (number)	Species treated	Preservative: Coal-tar creosote	Preservative: Petroleum	Preservative: Coal tar	Preservative: Zinc chloride solution	Preliminary air pressure [1]	Treating pressure [2]	Preservative temperature	Final vacuum [3]	Net absorption of oil or dry salt
		Percent	*Percent*	*Percent*	*Percent*	*Pounds per square inch*	*Pounds per square inch*	*°F.*	*Hours*	*Pounds per cubic foot*
2	Pine, southern yellow.	80		20		80–90	150–200	185–210	1 –1½	6
1	do	80		20		75–80	175–180	175–180	1 –1½	6
1	Pine, southern yellow (mostly sapwood).	80		20		100	175	190–200	1½	6
1	do				100		140–150	180	⅓– ½	½

PILING

Plants studied (number)	Species treated	Coal-tar creosote	Petroleum	Coal tar	Zinc chloride solution	Preliminary air pressure	Treating pressure	Preservative temperature	Final vacuum	Net absorption
1	Pine, lodgepole	100				50–75	190–200	180	1½	12–14
1	Pine, ponderosa	100				50–75	190–200	180	1½	12–14

TABLE 20.—*Commercial treating conditions and absorptions in use for species in the Eastern and Southern States*

AIR-SEASONED TIES [1]

Plants studied (number)	Species treated	Preservative: Coal-tar creosote	Preservative: Coal tar	Preservative: Petroleum	Preliminary air pressure	Maximum treating pressure [2]	Preservative temperature	Net absorption
		Percent	*Percent*	*Percent*	*Pounds per square inch*	*Pounds per square inch*	*°F.*	*Pounds per cubic foot*
1	Beech	60	40		(3)	175	195	8–9
1	Birch	60	40		60–65	200	175–190	6–7
1	do	60	40		(3)	175	195	8–9
1	Gum	80	20		50–60	150–200	150–210	6
1	do	80	20		70–80	250	180–190	6
1	do	80	20		45–65	165	190–200	8
1	do	70		30	50	225	190	7
1	do	100			75–90	175–200	190–200	5–6
1	do	80	20		70–80	250	180–190	6
1	do	70	30		85	175	190–200	8–9
2	do	80	20		75–90	175–200	190–200	5–8
1	Maple	60	40		60–65	200	175–190	6–7
1	do	60	40		(3)	175	195	8–9
1	Oak, red and white	80	20		75	175	160–170	5, 6, 8
1	do	60	40		60–65	200	175–190	6–7
1	do	60	40		(3)	175	195	8–9
1	do	80	20		35–40	200	190–200	8
1	Oak, red	100			25–50	150–175	180	5
3	do	80	20		50–60	150–200	185–210	6
1	do	100			50–65	200–250	200	5
1	do	80	20		50–65	200–250	200	6
1	do	80	20		50–60	175–180	175–180	6
1	do	80	20		80–90	250	180–190	6
1	do	80	20		45–65	165	190–200	8
1	do	70	30		20	170	180	6½–7
1	do	100			60–80	150	180–185	6
1	do	70	30		(3)	175	190–200	6–9
1	do	70		30	(3)	225	190	7
1	Pine, southern yellow	100			90–100	200	190–200	5–6
1	do	70		30	50	225	190	7
1	do	60	40		60–65	200	175–190	6–7
2	do	100			70–80	150	180–190	6
1	do	100			30–90	175	190–200	5
1	do	100			50–60	175–200	160–170	8
2	do	80	20		50–75	175	175–180	6
1	do	80	20		75	175	160–170	5, 6, 8

[1] Pressure period for hardwood ties 1 to 5 hours; for softwood ties 1 to 3 hours.
[2] Final vacuum periods varied from ¼ to maximum of 2½ hours, with average period not exceeding 1 hour.
[3] Atmospheric pressure (Lowry process).

TABLE 20.—*Commercial treating conditions and absorptions in use for species in the Eastern and Southern States*—Continued

AIR-SEASONED TIES—Continued

Plants studied (number)	Species treated	Preservative			Preliminary air pressure	Maximum treating pressure [2]	Preservative temperature	Net absorption
		Coal-tar creosote	Coal tar	Petroleum				
		Percent	*Percent*	*Percent*	*Pounds per square inch*	*Pounds per square inch*	*°F.*	*Pounds per cubic foot*
6	Pine, southern yellow	80	20		60–90	150–200	150–210	6
3	do	70	30		30–80	170–175	180–200	6–7
1	do	80	20		70–80	150	200–215	6
3	do	80	20		80–100	175–200	175–200	6–8
1	do	80	20		90–100	200	190–200	8
2	do	100			75–100	175–200	190–200	6
1	do	80	20		75–80	175–180	175–180	6
1	do	80	20		115	250	180–190	6
1	do	80	20		70–80	165	190–200	8
1	do	100			75–100	275–300	200	6
	STEAMED GREEN CROSSARMS [4]							
1	Pine, southern yellow	100			(5)	75–100	190	8 and 12
2	do	100			(5)	175	175–180	8 and 12
1	do	100			(5)	90–100	175–180	12
	STEAMED GREEN CONDUIT PIPE [6]							
1	Pine, southern yellow	100			60–70	75–125	180–185	6
1	do	100			40	75–90	180–190	8 and 12
	GREEN LUMBER AND BRIDGE TIMBRES [7]							
1	Pine, southern yellow	100			(5)	175	180	12–16
1	do	100			(5)	175	190	15–20
1	do	100			(5)	75–100	190–200	12
1	do	100			(5)	175	175–180	12
1	do	100			(5)	175	200	12
1	do	100			50–100	175	180	5–12
1	do	100			(5)	175–200	180–185	10–12
1	do	100			(5)	175	195–200	12
1	do	100			(5)	150	180–185	12
1	do	100			(5)	100–175	185–195	12–16
1	do	100			15	125	200	10–12
1	do	100			(5)	100	180–190	12
	STEAMED GREEN PILING AND POLES [8]							
1	Pine, southern yellow	100			50–60	150–200	185–200	8–22
1	do	100			60–65	175	190	5–6
1	do	100			50–75	160–175	190–210	8–12
1	do	100				175	175–180	8–16
1	do	100			40–80	165	200	8–12
1	do	100			10–30	200	200	8–16
1	do	100			(5)	125	170–175	12–22
1	do	100			25–60	150–200	190–200	8–16
1	do	100			35–90	200	180–200	8–15
2	do	100			40–60	165–175	180–200	8–12
1	do	100			10–50	170	180	8–12
1	do	100			10–25	100–130	180–190	8–12
1	do	100			30–60	90–175	180–185	8–12
1	do	100			20–30	175–200	180–185	8–22
1	do	100			70	175	195–200	6–12
1	do	100			(5)	150	180–185	12–20
1	do	100			30–50	150–200	185–190	8–12
1	do	100			15	125	200	8–12
1	do	100			50–100	190–225	190	8–24
1	do	100			75–100	275	200	8–12
1	do	70		30	25	150	190	16–20
1	do	100			(5)	150	190	25
1	do	80	20		(5)	100–125	180–190	12–20
1	do	100			(5)	175	160–170	16
1	do	100			25–50	175	175–180	8
1	do	100			60–75	200	200	8

[4] Pressure period ½ to 2 hours.
[5] The full-cell treatment usually employed for absorptions over 12 pounds per cubic foot.
[6] Pressure period ½ to 1 hour.
[7] Pressure period ½ to 3 hours.
[8] Pressure period 1 to 6 hours.

SPECIFICATIONS FOR TREATMENT

GENERAL CONSIDERATIONS

A large proportion of the wood that is treated commercially is treated under purchasers' specifications. Sometimes the specifications employed are the general specifications developed by various associations that are interested. In other cases the purchaser develops his own specifications and puts into them the provisions that he considers important. Very frequently, whatever the source, the specification fails to protect the purchaser, or contains provisions that are actually harmful to the wood or unnecessarily increase the cost of the treatment. Competent inspectors placed at the treating plants by the purchaser can enforce compliance with most of the requirements of a specification but even then the treatment will be unsatisfactory unless the specification is properly prepared or the treating-plant operator gives good treatment despite the specification.

As far as is practicable the author of a treating specification should take into consideration the following items: Species, form and dimensions of the timber to be treated, proportion of heartwood and sapwood, degree of seasoning at the time of treatment, method of seasoning or conditioning for treatment, purpose for which the treated timber is to be used, kind of preservative, absorption, penetration, and the details of the treating process. The specification, however, should avoid unnecessarily fixing the details of the treating operation. Provision should be made against the use of temperatures, pressures, and treating periods that are likely to damage the wood but within these limits the plant operator should be given as much freedom as practicable. As far as possible the specification should cover the finished product rather than minor details of the treating process. It should also clearly define the methods that will be used in judging the quality of the finished product. In developing new specifications or improvements to old specifications there should be cooperation and thorough understanding between the purchaser and the treating-plant operator to be sure that the requirements of the specification are reasonable and can be fulfilled. The general specifications that have been adopted by the American Wood Preservers' Association and other associations afford a good starting point, but they are necessarily quite general in character and must often be modified or limited in some respects in order to meet the needs of the individual purchaser.

AVOIDING INJURIOUS TREATING CONDITIONS

While the knowledge of wood-impregnating technic is still too incomplete to show the dividing line between safe and unsafe conditions, enough is known to permit some very definite limitations. In the steaming-and-vacuum process of conditioning green timber various steaming pressures and lengths of steaming periods have been used. With our present state of knowledge, however, there appears to be no good reason why steaming pressures above 20 pounds gage pressure (about 259° F.) should be employed. No advantage that might be gained by higher pressures is known that would offset the greater danger of the higher temperatures damaging the timber. Further study and experience may show that the use of pressures lower than 20 pounds will be practical and preferable.

Since steaming practice is now confined largely to green southern yellow pine the data given in figures 9 to 14 and 17 to 22 can be very useful as a guide in selecting a steaming period. From these temperature curves it may be noted that timbers of small dimension, such as those 6 inches or less in diameter and sawed material 3 inches or less in thickness, can be heated in a very short time so that the temperature at the center is nearly equal to that of the outside steam temperature. With a steam pressure of 20 pounds about 4 to 5 hours steaming should be ample for timbers about 6 to 7 inches in diameter, about 1½ to 2 hours for lumber 2 inches in thickness, about 2 to 3 hours for lumber 3 inches in thickness, and 3 to 4 hours for material 4 inches in thickness. The foregoing time intervals assume that full steam temperature is applied at once. In actual practice from one-half to 1 hour additional may be required to reach the maximum steam temperature. It is important that sawed material be properly spaced or "stickered" in loading the trams so that the steam can circulate freely around every piece; otherwise longer steaming periods will be required and uniform distribution of heat throughout the charge may not be obtained.

In the larger sizes it becomes impractical and also unnecessary to heat the center to a temperature approaching that of the heating medium. It is impractical because of the very long heating periods required and the injury that might result to the wood. It is also unnecessary because the heat at the interior of the large timber cannot be very effective in evaporating moisture during the subsequent vacuum period. While it is not known just what the temperature should be at a given distance from the surface to obtain the most effective results, it is probable that very little would be gained in heating the wood much above 200° F. at a distance of about 3 inches from the surface. In some of the larger sizes of timber it would be necessary to be satisfied with even lower temperatures at this depth because of the undesirably long heating periods otherwise required. Under special conditions, for example, when the purchaser requires that the heating be continued until the wood is sterilized a considerable distance from the surface, longer steaming periods may be required but they should be used only with the full knowledge of both operator and purchaser that the risk of damage increases as the steaming period is lengthened.

In conditioning wood by the Boulton process, time and temperature are again the important factors to control in avoiding damage. The specifications of the American Wood Preservers' Association permit a maximum oil temperature of 220° F. during the boiling-under-vacuum period when treating Douglas fir poles and piling and 200° when treating Douglas fir lumber and sawed timbers. In the light of present information these temperatures should not be exceeded and it may be found practicable in the course of time to reduce them.

The same specifications provide that the boiling under vaccum shall be continued until the amount of water collected is approximately one-tenth pound per cubic foot of wood per hour. For reasons previously discussed, variable results will necessarily be obtained even when this requirement is included in the specification. Furthermore, it is not established that it is necessary to continue the boiling to this point and it seems quite probable that, in some cases at least, the boiling can be discontinued sooner. No maximum time limit is

ordinarily provided in the specifications but dependence is placed on the fact that the plant operator is not likely to continue the vaccum longer than necessary for that would mean unnecessary expense.

Treating pressures specified should be maximum allowable pressures; not required pressures. The plant operator should be allowed to use any pressure within the maximum limit that will give the required absorptions and penetrations and avoid damage to the timber.

The maximum pressures employed in practice for various species are given in tables 18 to 20, inclusive. Some of these pressures, however, have been found to be too high if applied for a considerable period or when used with preservative temperatures that are more favorable for treatment. With preservative temperatures of 195° to 200° F., gage pressures of 100 to 125 pounds are generally as high as should be used in the full-cell treatment of low-density species like the spruces and true firs. This also applies to other species that show susceptibility to checking and collapse during treatment. In the empty-cell treatment of such woods the maximum preservative pressure will depend somewhat on the initial air pressure but it should always be less than an amount equal to the pressures recommended for a full-cell treatment plus the initial air pressure. For example, if an initial air pressure of 50 pounds per square inch is used the preservative pressure should not be much over 150 pounds as a maximum with low-density woods. The more dense woods can, of course, withstand somewhat higher pressures but if it is found that collapse or checking occur during treatment the preservative pressure should be lowered.

SELECTION OF TREATING PROCESS

There is often considerable misunderstanding regarding the relative merits of the full-cell and empty-cell methods of treatment. The effectiveness of treatment depends upon the preservative, absorption, and depth of penetration and not upon the treating process except as the process used may affect penetration and the absorption specified.

The names full cell and empty cell, as applied to treatment, are very misleading since the so-called "full-cell" process does not leave the wood cells completely filled with preservative even when an effort is made to obtain this objective. Likewise the so-called "empty-cell" processes do not leave the wood cells empty of preservative regardless of the absorptions or initial air-pressure conditions employed. Strictly speaking, there is no actual full-cell or empty-cell treatment. It should be borne in mind that the principal difference between the full-cell and empty-cell processes is in the relative amount of air retained in the wood cells at the time the preservative is injected. The difference in the results obtained is that the full-cell process gives a greater concentration of preservative in the treated portion than does the empty-cell process. Higher gross absorptions and hence deeper penetrations are normally obtained by the empty-cell treatment unless very high net retentions are specified. In selecting the treating process the object in all cases should be to obtain the maximum penetration practicable with the absorption specified. This important consideration has been frequently overlooked in many specifications. Some have required full-cell treatment of timbers that are largely sapwood and with this have stipulated that all sapwood be penetrated. These specifications, however, have at the same time named

net retentions that will not permit complete sapwood penetration by the full-cell method. An empty-cell treatment should be employed whenever the penetration can be improved and there is no justification in restricting the plant operator to the use of the full-cell process when a limited absorption is stated. Full-cell treatment should be specified only when the maximum possible net absorption is desired. The treating-plant operator should, however, be allowed to use the full-cell process when, because of a limited amount of sapwood, resistance of the material, or for other reasons, the specified net absorption cannot be obtained by an empty-cell treatment.

UNNECESSARY REQUIREMENTS

A serious fault with some specifications is that they attempt to fix all the details of treatment regardless of the fact that even when the same species and same class of timber are treated, each charge may require some modification of the treating conditions to obtain satisfactory results. For example, in the treatment of green material some timbers will require different steaming or boiling-under-vacuum periods depending on the size of the timber, moisture content, amount of sapwood and heartwood, and other variables. Similarly, a certain degree of latitude should be permitted in the treating pressures and pressure periods employed because pressure conditions that give good results for some timbers may prove unsatisfactory for others. Specifications, however, should set maximum limits on the steaming pressure, steaming periods, and similar treating operations that may affect the condition of the timber. An attempt is sometimes made to insure deep penetrations by specifying the gross absorption as well as the net retention. Since the net retention may vary widely for any given gross absorption such specifications are impractical and often impossible to meet. Again, if the sapwood is not very deep or if the wood has a high moisture content when treated, it may be impossible to get the required gross absorption. In any case it is sufficient to specify the net retention and whatever penetration can reasonably be required.

Specifications sometimes severely limit the amount of sapwood permitted in the timber. As a rule, this merely adds to the cost of the timber, makes it more difficult to get, and may result in poorer treatment than if no limit is placed on the amount of sapwood. This provision is evidently carried over from specifications covering timber to be used without preservative treatment when the proportion of heartwood had a marked influence on the decay resistance of the wood. Preservatives, however, make sapwood as durable as heartwood and since sapwood takes better absorptions and penetrations than heartwood there is seldom good cause to require a high percentage of heartwood in timber that is to be treated. Since the mechanical properties of sapwood average as high as those of heartwood, strength requirements afford no basis for discriminating against sapwood.

With good vacuum pumps, long vacuum periods are apparently unnecessary at any stage in the treating operation with the exception of the boiling-under-vacuum process. Preliminary vacuum for full-cell treatment of air-seasoned material needs to be extended little, if any, beyond the point when approximately the maximum vacuum is reached. In order to allow sufficient time for the excess preserv-

ative to drip from the wood, final vacuums after full-cell or empty-cell treatments sometimes need to be held longer than a preliminary vacuum.

The vacuum applied after steaming should not be held longer than necessary to obtain a practicable moisture reduction since after a time the effect is merely to cool the wood without appreciably lowering the moisture content. Sufficient experimental work has not yet been done to determine the most effective vacuum periods for various sizes of timber but the data at hand indicate that some plants use vacuum periods that are longer than needed to accomplish the best results.

ABSORPTIONS

TIES

Coal-tar creosote, mixtures of coal-tar creosote and coal-tar, and zinc chloride have been widely used in the treatment of ties and the relative merits of these preservatives have been fairly well determined from experience. Within recent years a considerable number of plants in the Pacific Coast and Rocky Mountain States have been treating ties with mixtures of petroleum and coal-tar creosote. It is known that these mixtures are capable of giving good results, but sufficient data are not yet available to determine definitely how they will compare with other preservatives or what are the best absorptions to use.

Table 21 gives data obtained between 1929 and 1934 on the absorptions and preservatives specified for ties and employed in treatments made at 55 representative treating plants located in different parts of the United States. Of the plants listed, 11 were using coal-tar creosote, 18 creosote-petroleum mixtures, and 26 creosote-coal-tar solutions. Some of these plants also were using zinc chloride for ties that were to be placed in certain localities.

Table 21.—*Preservative oils and absorptions used for ties*

[Data from 55 plants]

Plants (Number)	Coal-tar creosote	Mixture		Mixture		Specified absorption
		Coal-tar creosote	Petroleum	Coal-tar creosote	Coal tar	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Lb. per cu. ft.*
3	100					5
5	100					6
2	100					6–8
1	100					8–9
1		40	60			7–8
3		45	55			7–8
6		50	50			7–8
2		50	50			7–8
1		55	45			7
4		70	30			7–8
1		70	30			5–6
1				60	40	6–7
1				60	40	8
1				60	40	8–9
3				70	30	6–7
1				70	30	8–9
2				80	20	5–6
13				80	20	6
3				80	20	8
1				80	20	5–8

The creosote-petroleum mixtures are extensively used in the Western and Rocky Mountain States and the creosote-coal-tar solutions in the Eastern and Southern States. Most of the ties impregnated with preservative oils are treated by the empty-cell method (Lowry or Rueping process) and the specified net retentions usually vary from about 5 to 8 pounds per cubic foot. Absorptions of 5 to 6 pounds appear to be too low for ties that can be deeply penetrated, such as red oak or sapwood material.

Although the empty-cell treatment may give good penetrations when the wood has been properly seasoned, the possibility of erratic penetrations is great when low net absorptions are used. The chance of erratic penetration decreases with higher absorptions. The question also arises whether with complete penetration the concentration of preservative with these low absorptions is sufficient to protect the ties over the period of service that should be expected of properly treated wood. Ties that have a considerable proportion of heartwood, when treated with the lower absorptions would naturally have a greater concentration of preservative in the treated part than those that take practically complete penetration. The life obtained from the heartwood ties having a heavy concentration of preservative might be much longer than would be obtained from sapwood material or woods that take practically complete penetration unless the absorption in the latter was increased to compensate for the greater amount of wood treated.

In view of the unsatisfactory results that have been noted in some installations of ties treated with the low net retentions of 5 to 6 pounds of preservative oil per cubic foot it is recommended that specifications should require a net retention of at least 8 pounds per cubic foot in ties having 50 percent or more sapwood or when the species is one that can be well penetrated in the heartwood. Some specifications call for 5 to 6 pounds of creosote per cubic foot on the assumption that the greater toxicity of creosote, as compared with that of creosote mixtures containing coal tar or petroleum, will permit these lower absorptions when creosote alone is used. Successful results are not assured by a consideration of toxicity only, since permanence plays a very important part. Data on leaching and evaporation indicate that doubling the absorption should increase permanence fourfold. If the ties are used under tropical or semitropical conditions minimum absorptions of 10 to 12 pounds of preservative per cubic foot, or treatment with the maximum absorption obtainable, are recommended regardless of whether the creosote is used alone or in mixtures.

Specifications for the treatment of ties and other timbers with zinc chloride have commonly required one-half pound of dry salt per cubic foot regardless of the amount of sapwood or heartwood. While this absorption might be found satisfactory for heartwood timbers in which only the outer portion is treated, it would give very different results if the timbers were largely sapwood or if the heartwood were readily penetrated, as in red oak. As in the case of preservative oils such variable concentrations may result in a corresponding variability in resistance to decay. There is a tendency at the present time to favor somewhat higher absorptions, such as three-fourths to 1 pound per cubic foot.

If a careful study were made of premature failures of ties treated with preservative oils or with water-soluble salts, it is probable that

with the exception of those removed on account of accidents or because they were not sound at the time of treatment, insufficient absorptions would be found to be the most common cause of such failures.

MARINE TIMBERS

The protection of wood against marine borers is a much more difficult problem than protection against decay and insects and requires much higher concentration of the preservative. The Forest Products Laboratory has tested a large number of preservatives to study their effectiveness in protecting wood against marine borers (*24*). Results obtained in these experiments, as well as experience in general, have shown that heavy absorptions of coal-tar creosote are essential if the best protection is to be obtained. The heavy absorptions insure better penetrations and also furnish a reserve supply of creosote to provide against early depletion by leaching. In a large portion of the coastal region of the United States marine timbers are exposed to severe borer attack and under such conditions it is poor economy to specify absorptions that will not give the maximum protection. Specifications for such timbers should require treatment to refusal by the full-cell process and the specified absorption should be the minimum, not the maximum.

The species most commonly used for marine timbers in the United States are southern yellow pine and coast Douglas fir. Southern yellow pine piling treated with the maximum retention practicable by the full-cell process usually has average net absorptions of 20 to 25 pounds of creosote per cubic foot provided the moisture content of the wood is not too high at the time of treatment. Since the depth of sapwood on Douglas fir piling is usually less than that on southern yellow pine, the net retentions are somewhat less in the Douglas fir for the same treatment. The maximum absorption that can be conveniently obtained in the Douglas fir piling may vary from about 16 to 18 pounds per cubic foot, depending on the size, moisture content, and depth of sapwood.

POLES AND LAND PILING

Most of the poles and piling treated under pressure are southern yellow pine and coast Douglas fir, although a few other woods are used in some localities. Straight coal-tar creosote is the preservative oil used for practically all pressure-treated poles. Absorptions of 8 to 10 pounds per cubic foot for southern yellow pine and about 8 pounds per cubic foot for coast Douglas fir poles are now commonly specified. Poles with these absorptions are treated by empty-cell processes. A few specifications require a full-cell treatment of 12 to 16 pounds per cubic foot in southern yellow pine poles. Since a 12- to 16-pound full-cell treatment often fails to give good sapwood penetration it is always desirable to use an empty-cell method whenever there is any possibility of obtaining better penetrations by so doing. Specifications, for most species used for land piling, generally require absorptions of about 10 to 16 pounds per cubic foot and both creosote and creosote-coal-tar solutions are used. Even a 16-pound full-cell treatment will often fail to give complete sapwood penetration in some poles and piling when the sapwood is deep. While a full-cell treatment will give a greater concentration of preservative in the

treated portion, an empty-cell treatment is preferable where there is any question about complete sapwood penetration with the absorption specified. Where particularly heavy concentrations of the preservative are needed absorptions should be specified that will insure good sapwood penetration with the full-cell treatment. This can be obtained most satisfactorily by requiring full-cell treatment to refusal (i. e., the maximum absorption that is practicable to obtain) and specifying the minimum rather than the maximum absorption.

SAWED TIMBERS

Coal-tar creosote and its mixtures are commonly employed for sawed material, such as bridge timbers, used under relatively severe conditions. Absorptions specified for such timbers vary from about 6 to 20 pounds per cubic foot with absorptions of about 10 to 12 pounds being most common. Both the empty-cell and full-cell methods are employed, depending on the amount of sapwood, absorptions required, size of timbers, and similar factors. The full-cell process is commonly employed in the treatment of resistant heartwood timbers.

Water-soluble salts find wide application in the treatment of sawed lumber used under conditions where it would be impractical to use preservative oils.

At the present time specifications for absorptions of both preservative oils and water-soluble salts often fail to take into consideration the relation of the timber dimensions to penetration and absorption (p. 81). Frequently the treating plant has been blamed for unsatisfactory treatment when the fault lies in the specification which does not call for a sufficient absorption to insure a good penetration. Again the specification may require a net retention in large heartwood timbers that cannot be obtained because of the small ratio of surface area to volume, although the same absorption might be obtained without difficulty in heartwood timbers of tie size or smaller or in large-sized timbers containing a large proportion of sapwood. Table 15 will be found useful in estimating the proportional absorption for various sizes of heartwood timbers. In timbers containing 50 percent or more sapwood it is recommended that at least 10 pounds of preservative oil or three-fourths pound of zinc chloride (dry salt) be specified per cubic foot of wood.

Small and large sizes of heartwood timber should not be treated in the same charge if it can be avoided, but sometimes the total volume of timber in an order is less than enough for one charge and it would be uneconomical to make more than one charge. In such cases the average absorption should be calculated on the proportions of small and large sizes as shown on page 85.

The tendency of some purchasers is to specify relatively low absorptions in the hope of reducing the cost to the lowest safe minimum. This proves to be false economy in many cases for the minimum safe absorption cannot be named with exactness for any form or use of treated timber. The cost of a little additional preservative is relatively small in comparison with the total cost of the treated timber in place in the finished structure and the saving in cost that may result from the use of low absorptions is very small in comparison with the risk of poor service from inadequate treatment. When long

service is required it is better to specify absorptions somewhat above rather than below the average in common practice.

The absorption must be determined by observations at the time of treatment. There is no practical way to determine by observation or analysis of the timber after treatment whether the required absorption was obtained. It is possible, of course, by extraction methods to determine approximately how much preservative is in a small sample of treated wood but there is no way to determine how nearly the sample is representative of the average of the charge. If cut near the end of a timber the sample may contain more than the average unit absorption for the timber and if cut from the center it may contain less than the average. The individual timber in turn may contain much more or much less than the average absorption for all the timbers in the charge. The purchaser of treated timber who expects to get the specified absorption in each timber in his order will be greatly disappointed for such a result cannot be achieved.

PENETRATION

Whenever practicable the minimum acceptable penetration and the minimum average penetration should be specified but this should be done with considerable care or the requirement may be impracticable. General specifications often require that all of the sapwood and as much of the heartwood as practicable shall be penetrated. Complete sapwood penetration is obtained many times in various sizes and shapes of timber but a strict enforcement of this requirement on every piece of timber treated would generally prove impractical. There should be a definite understanding between purchaser and plant operator as to what shall be acceptable and what shall not. A complication in this connection is that it is not always easy to locate in treated timber, the dividing line between heartwood and sapwood. To say that "as much of the heartwood as practicable shall be penetrated" is too indefinite and adds nothing of value in the specification. The only safe way is to require minimum and average penetrations in heartwood faces that are practical to obtain by good treating methods and that are suitable for the service desired of the timber. It is, of course, impractical to demand deep penetrations in boards or timber of small dimensions when insufficient absorptions are specified. This is especially true for heartwood material because of the smaller amount of kick-back from heartwood in comparison with that obtained from sapwood.

Penetrations of creosote and other dark-colored oils can be measured on increment borings or bit holes made at a sufficient distance from the ends of the piece to escape the effect of end penetration. The oil has a tendency to creep over the surface of the wood in a short time so that the observation should be made promptly after boring. With sufficient skill and a sharp knife or blade, the core taken out by the increment borer may be split open and a more accurate determination can be made of the penetration. This avoids the effect of oil creeping along the surface during the boring operation.

The penetration on borings from timber treated with water-soluble salts can usually be shown by spraying the boring with a solution that gives a distinct color reaction with the preservative. If timber treated with water-soluble salts is sawed for penetration measurements

before it is seasoned, the saw may carry some of the solution over the cut surface. This could very easily give an indicated penetration much deeper than is actually obtained. Even well-seasoned wood may have particles of sawdust carried over the surface from the treated portion which would give misleading results. It is therefore important to guard against conditions that will spread the preservative over unpenetrated wood when the timber is either bored or sawed for penetration measurements.

All holes made in treated timber for observing penetration should be tightly plugged with thoroughly treated plugs.

FRAMING AND BORING

Insofar as is practical the specifications should provide for complete framing and boring before treatment. This is much more practical than is ordinarily supposed (*27*, *29*). Cutting into timber after treatment is very likely to expose untreated wood and thus permit the entrance of decay or insects beneath the treatment. Cutting after treatment is especially dangerous in timber that will be exposed to marine borers.

FORMULAS

FORMULAS FOR COMPUTING RELATION OF MOISTURE CONTENT, SPECIFIC GRAVITY, AND AIR SPACE IN WOOD

The notations used have the following meaning:

M=percentage of moisture.
M_m=maximum percentage of moisture when air space is completely filled with water.
W=original weight of moisture specimen.
D=weight of moisture specimen when oven dried.
W_v=weight per unit volume of wood at any moisture content M.
W_m=weight of water in wood at moisture content M (weight per unit volume).
W_d=weight of oven-dry wood per unit volume at moisture content M.
W_w=weight per unit volume of water at maximum density (W_w equals 1 in the metric system and equals 0.0361 pound per cubic inch or 62.4 pounds per cubic foot in English system).
P=percentage of air space in wood having a specific gravity S and moisture content M.
1.55=specific gravity of wood substance.
P_w=percentage of volume occupied by moisture.
S=specific gravity based on the weight of the oven-dry wood and volume at moisture content M.
S_g=specific gravity based on the weight of the oven-dry wood and volume when green.
S_d=specific gravity based on the weight of the oven-dry wood and volume when oven dry.
S_k=specific gravity based on the weight of the oven-dry wood and volume at moisture content K below fiber-saturation point.
P_s=percentage of shrinkage in volume in seasoning from the fiber-saturation point to moisture content K.

SPECIFIC GRAVITY

$$S=\frac{W_d}{W_w} \qquad (1)$$

Where W_d and W_w are in pounds per cubic foot.

$$S=\frac{W_d}{62.4} \qquad (1a)$$

OVEN-DRY WEIGHT OF WOOD

$$W_d = W_v \div \left[1+\frac{M}{100}\right] = S\ (W_w) \qquad (2)$$

Where W_d is in pounds per cubic foot.

$$W_d = S\ (62.4) \qquad (2a)$$

MOISTURE CONTENT IN PERCENT

$$M = 100\left[\frac{W}{D}-1\right] = 100\left[\frac{W_v}{S(W_w)}-1\right] \qquad (3)$$

Where W_v is in pounds per cubic foot.

$$M = 100\left[\frac{W_v}{S(62.4)}-1\right] \qquad (3a)$$

MAXIMUM MOISTURE CONTENT IN PERCENT

$$M_m = 100\left[\left(W_w - \frac{W_d}{1.55}\right) \div W_d\right] = 100\left[\frac{1}{S}-\frac{1}{1.55}\right] \qquad (4)$$

WEIGHT OF WATER PER UNIT VOLUME OF WOOD

$$W_m = (W_v - W_d) = W_w\left[\frac{MS}{100}\right] = W_d\left(\frac{M}{100}\right) \qquad (5)$$

Where W_m is in pounds per cubic foot.

$$W_m = 62.4\left[\frac{MS}{100}\right] \qquad (5a)$$

PERCENTAGE OF VOLUME OCCUPIED BY MOISTURE

$$P_w = 100\left[\frac{W_v - W_d}{W_w}\right] = MS \qquad (6)$$

Where W_v and W_d are in pounds per cubic foot.

$$P_w = 100\left[\frac{W_v - W_d}{62.4}\right] \qquad (6a)$$

TOTAL WEIGHT OF WOOD AND WATER AT ANY MOISTURE CONTENT M

$$W_v = \left[W_d + \frac{MW_d}{100}\right] = S(W_w)\left[1+\frac{M}{100}\right] \qquad (7)$$

Where W_v and W_d are in pounds per cubic foot.

$$W_v = S(62.4)\left[1+\frac{M}{100}\right] \qquad (7a)$$

PERCENTAGE OF AIR SPACE IN WOOD

$$P = 100\left[1-\left(\frac{W_d}{W_w(1.55)}+\frac{W_v - W_d}{W_w}\right)\right] \qquad (8)$$

$$= 100\left[1-\left(\frac{S}{1.55}+\frac{MS}{100}\right)\right]$$

PERCENTAGE OF SHRINKAGE IN VOLUME IN SEASONING FROM FIBER-SATURATION POINT TO MOISTURE CONTENT K

$$P_s = 100\left[\frac{S_k - S_o}{S_k}\right] \qquad (9)$$

SPECIFIC GRAVITY AT ANY MOISTURE CONTENT K BELOW THE FIBER-SATURATION POINT

$$S_k=\left[S_d-(S_d-S_o)\frac{K}{25}\right] \qquad (10)$$

FORMULA FOR COMPUTING TEMPERATURES IN TIMBERS WHEN THE TEMPERATURE OF THE HEATING MEDIUM, THE WOOD TEMPERATURE, OR BOTH ARE DIFFERENT FROM THOSE USED AS A BASIS FOR COMPUTING DATA FOR FIGURES 9 TO 15 AND 17 TO 22, INCLUSIVE

The notations used have the following meaning:

U_o=Initial wood temperature assumed in computing tables=60° F.
U_1=heating medium temperature assumed in computing temperatures in wood=260° F.
$U^1{}_o$=any given initial wood temperature. Values of $U^1{}_o$ are read on the left vertical scale of figure 16.
U_2=any given heating medium temperature. Values of U_2 are read on the right vertical scale of figure 16.
U=temperature obtained in a given time t at the point under consideration when the initial wood temperature U_o=60° and the heating medium temperature U_1=260° F. Values of U are computed and are plotted in figures 9 to 15 and 17 to 22, inclusive. Values of U are read on the bottom scale of figure 16.

Values for U are to be taken from the proper figure showing point under consideration. For example, for steamed green round southern pine timbers or green Douglas fir timbers heated in creosote, values of U are to be taken from figures 9 to 14, inclusive. For green sawed timbers of these species values of U are to be taken from figures 17 to 22.

U_x=temperature obtained at a given distance from the surface when the heating medium temperature U_2, wood temperature $U^1{}_o$, or both are different from the heating temperature U_1 and initial wood temperature U_o, the temperature conditions that give the values of U shown in figures 9 to 15 and 17 to 22, inclusive.

The following relation exists among the factors defined in the preceding notation:

$$U_x=U_2-\frac{(U_2-U^1{}_o)}{(U_1-U_o)}(U_1-U) \qquad \text{(a)}$$

If it is desired to find the time necessary to reach an assumed value for U_x solve for U and find, from the proper figure, the time t required to reach the temperature U. This time will evidently be the same as that required to reach a temperature U_x at the same point when the heating medium temperature is U_2 and the initial wood temperature $U^1{}_0$.

From the foregoing equation solving for U:

$$U=U_1-\frac{(U_2-U_x)}{(U_2-U^1{}_0)}\;(U_1-U_0) \qquad \text{(b)}$$

EXAMPLES ILLUSTRATING THE USE OF FORMULAS (a) AND (b)

EXAMPLE 1

A green southern pine pole 10 inches in diameter is steamed at 260° F. with the initial temperature of the wood 30°. What is the temperature at a distance of 2 inches from the circumference after steaming for 5 hours?

Figure 9 shows a temperature of 204° F. at this distance when the initial wood temperature was 60° and the steam temperature 260°.

With the conditions given,

$$U_0=60°\text{ F.}\quad U_1=U_2=260°.\quad U^1{}_0=30°.\quad U=204$$

Substituting in equation (a)

$$U_x = 260 - \frac{(260-30)}{(260-60)}\ (260-204) = 260-64.4 = 195.6°\ \text{F.}$$

A temperature of about 196° F. is therefore shown for the temperature conditions assumed.

EXAMPLE 2

Assume the same conditions as in example 1 except that the steam temperature is 274° F. (about 30 pounds gage pressure). In this case $U_0=60$, $U^1{}_0=30$, $U_1=260$, $U_2=274$, and $U=204$. Solving for U_x (equation (a)),

$$U_x = 274 - \frac{(274-30)}{(260-60)}\ (260-204) = 274-68.3 = 205.7$$

or about 206°. This is an increase of about 10° because of using the higher steam temperature than was assumed in example 1.

EXAMPLE 3

How long must a green sawed southern pine timber 8 by 16 inches in cross section be steamed to reach a temperature of 200° F. at a distance of 2 inches from the surface when the initial wood temperature is 50° and the steam temperature is 240° (about 10 pounds gage pressure)?

In this case $U_x=200$, $U_0=60$, $U^1{}_0=50$, $U_1=260$, $U_2=240$.

Solving for U, equation (b),

$$U = 260 - \frac{(240-200)}{(240-50)}\ (200) = 260-42.1 = 217.9$$

or approximately 218° F. The time required to reach a temperature of 200° with the initial wood temperature 50° and the steam temperature 240° is the same as the time required to reach the temperature U (218°) with the steam temperature of 260° and the initial wood temperature at 60°. Figure 19 is to be used to find the time required to reach 218° at 2 inches from the surface. This is found to be about 9 hours. It would therefore require nearly 9 hours to reach a temperature of 200° with the steam and initial wood temperatures assumed.

EXAMPLE 4

An 8 by 8 inch green Douglas fir timber is heated in creosote at 220° F. for 6 hours. If the initial wood temperature is 45°, what is the temperature at the center after this heating period?

From figure 19 it is found that a temperature of about 208° F. is reached in this time with the initial wood and heating temperatures of 60° and 260°, respectively.

In this case $U_0=60$, $U_1=260°$ F., $U_2=220$, $U^1{}_0=45$, $U=208$. Solving for U_x (equation (a)),

$$U_x = 220 - \frac{(220-45)}{(260-60)}\ (260-208) = 220-45.5$$

$$=174.5 \text{ or approximately } 175°\ \text{F.}$$

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